Welding

Tenth edition

A. C. Davies

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Contents

Part 2 The practice of welding

Preface

The Science and Practice of Welding has a very long and distinguished history. First published in 1941 it reached its tenth edition in 1993. During its life the book has grown in size, and for the eighth edition was divided into two volumes: *Welding Science and Technology* and *The Practice of Welding.* For this Cambridge Low Price Edition the two volumes have been amalgamated once more to give a single comprehensive volume, and two new appendixes have been added, one on the generation and purification of acetylene, and one on forge welding.

My thanks are due to the following firms for their help and cooperation by supplying much technical information and photographs as indicated:

AGA Gas Ltd: Industrial gases

Air Products Ltd, Crewe: special gases and mixtures, welding of aluminium, stainless and heat resistant steels.

Air Products Ltd, Ruabon: welding of aluminium and its alloys, stainless and 9% nickel steels and plasma cutting.

Alcan Wire Ltd: aluminium welding techniques and applications.

Alpha Electronics for information on measuring instruments.

Aluminium Federation: classification and properties of aluminium and its alloys. Welding techniques and applications.

American Welding Society: welding symbols and classifications.

Amersham International: X-ray and gamma-ray testing of welds, and gamma-ray sources.

Andrex Products (NDT) Ltd: sources of X-rays and the testing of welds, with illustrations.

Babcock Wire Equipment Ltd: cold presssure welding with photographs.

Baugh and Weedon Ltd: ultrasonic testing of welds, with photographs.

Bernard Division, Armco Ltd: MIG welding guns.

Bielomatic London Ltd: ultrasonic, hot plate and linear vibration machines and photographs.

BOC Ltd: technology of stainless steel; and BOC Ltd (Gases Division): gas technology.

Brush Electrical Machines Ltd: details of thyristor controls.

Bullfinch Gas Equipment Ltd: brazing techniques and torch photographs.

Butters' Welding Equipment (Eland Group): power units.

Copper Development Association: classification of copper and its alloys.

Deloro-Stellite Ltd and Cabot Corporation: wear technology and laying down of wear resistant surfaces.

Distillers AG Ltd: industrial gases, heaters and gauges for CO_2 cylinders.
ESAB Ltd: TIG and MIG and submerged arc processes and accessories including backing strips, robot welding systems and MIG applications, power units for MMA, MIG and TIG welding, positioners, manipulators and add on units, photographs of equipment.
Filarc Welding Industries BV (successors to Philips Export BV): low hydrogen electrode, downhill pipeline welding.
Goodburn Plastics Ltd: information and photographs of torches, nozzles and HF spark tester.
Hermann Ultrasonics Ltd: resonant unit for plastic welding.
Hobart Brothers Co Ltd: illustration of synergic welding unit and MIG unit wire drive.
INCO Alloys International Ltd, Hereford: details of the nickel–copper, chromium–nickel and nickel–chromium–iron alloys.
Interlas Ltd: Miller synchrowave TIG unit and Pulsar MIG unit techniques and photographs of welding units including those of Miller (US) and Hitachi.
Johnson Matthey and Co: brazing alloys and fluxes.
Loctite UK Ltd: technology and photographs of plastics joining adhesives.
Magnesium Elektron Ltd: classification and properties of magnesium and its alloys.
Megger Instruments Ltd: instrument technology.
Murex Welding Products: thyristor control of welding sources; chemistry of submerged arc fluxes. MIG and TIG welding units, synergic welding plant and photographs; 230 bar gauges (Saffire) and photographs; sub arc fluxes; technology of air plasma cutting and photographs of plant.
Nederman Ltd: sketches of fume extraction plant.
Oerlikon Buhrle Ltd: electrode coatings and their manufacture.
Palco Ltd: details of seam tracking and automatic magnetic arc welding with illustrations.
Power Con Incorporated (US): photographs of power units.
Radiographic Supplies Ltd: diagrams and information on magnetic particle, ultrasonic and dye penetrant testing of welds.
Salford Electical Instruments Ltd: link testing ammeter.
Stewart and Lloyds Plastics Ltd: technology and photographs of electro-fusion and hot plate welding of plastics.
Testrade Ltd: information and photographs of gamma-ray testing of welds.
Union Carbide Co. Ltd: plasma cutting and photographs.
Welding Institute: information on crack tip opening displacement: information and photograph on alloy steel electrodes; photographs of laser welds.
Welding Torches Co Ltd (WTC) Wigan: technology and photographs of air plasma welding and cutting.
Welwyn Tool Co Ltd: technology and photographs of Leister plastic welding equipment.
Wescol Ltd: photographs of gauges for gases and flashback arrestor.
Wharton Williams Taylor 2W: underwater welding and cutting techniques.
G. J. Wogan Ltd: information and testing of welds, with photographs.

My thanks are also due to Messrs D. G. J. Brunt, A. Ellis, C. Owen, M. S. Wilson, R. A. Wilson and Dr S. J. Garwood for technical help received in the preparation of the ninth edition; to Messrs R. P. Hampson, R. Moulding, J. B. Stokes and P. V. C. Watkins for the tenth edition; to Messrs J. Crouch, H. J. Davies (Murex Welding Products ESAB (UK)), J. B. Stokes and W. F. J. Thomas for help in compilation of information; to Mr P. V. C. Watkins for help with the section on the synergic MIG welding process; to Messrs R. P. Hampson and R. M. Wilson for help with Appendix 5; to Mr H. J. Davies for general help and information on air plasma cutting; to Mr A. Ellis for general help in air plasma cutting and the welding of plastics; and to Mr J. B. Stokes for help with the appendix on forge welding.

Fourth edition 1955, 1959 A. C. Davies

The metric system and the use of SI units

The metric system was first used in France after the French Revolution and has since been adopted for general measurements by all countries of the world except the United States. For scientific measurements it is generally used universally.

It is a decimal system, based on multiples of ten, the following multiples and sub-multiples being added, as required, as a prefix to the basic unit.

Prefixes for SI units

Prefix	Symbol	Factor
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}

Examples of the use of these multiples of the basic unit are: hectobar, milliampere, meganewton, kilowatt.

In past years, the CGS system, using the centimetre, gram and second as the basic units, has been used for scientific measurements. It was later modified to the MKS system, with the metre, kilogram and second as the

basic units, giving many advantages, for example in the field of electrical technology.

Note on the use of indices

A velocity measured in metres per second may be written m/s, indicating that the second is the denominator, thus: $\frac{\text{metre}}{\text{second}}$ or $\frac{\text{m}}{\text{s}}$. Since $\frac{1}{a^n} = a^{-n}$, the velocity can also be expressed as metre second^{-1} or m s^{-1}. This method of expression is often used in scientific and engineering articles. Other examples are; pressure and stress: newton per square metre or pascal (N/m^2 or Nm^{-2}); density: kilograms per cubic metre (kg/m^3 or kg m^{-3}).

SI units (Système Internationale d'Unités)

To rationalize and simplify the metric system the Système Internationale d'Unités was adopted by the ISO (International Organization for Standardization). In this system there are six primary units, thus:

Quantity	Basic SI unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd

In addition there are derived and supplementary units, thus:

Quantity	Unit	Symbol
plane angle	radian	rad
area	square metre	m^2
volume*	cubic metre	m^3
velocity	metre per second	m/s
angular velocity	radian per second	rad/s
acceleration	metre per second squared	m/s^2
frequency	hertz	Hz
density	kilogram per cubic metre	kg/m^3
force	newton	N
moment of force	newton per metre	N/m
pressure, stress	newton per square metre	N/m^2 (or pascal, Pa)

Quantity	Unit	Symbol
surface tension	newton per metre	N/m
work, energy, quantity of heat	joule	J (N/m)
power, rate of heat flow	watt	W (J/s)
impact strength	joule per square metre	J/m^2
temperature	degree Celsius	°C
thermal coefficient of linear expansion	reciprocal degree Celsius or kelvin	$°C^{-1}$, K^{-1}
thermal conductivity	watt per metre degree C	W/m °C
coefficient of heat transfer	watt per square metre degree C	W/m^2 °C
heat capacity	joule per degree C	J/°C
specific heat capacity	joule per kilogram degree C	J/kg °C
specific latent heat	joule per kilogram	J/kg
quantity of electricity	coulomb	C (As)
electric tension, potential difference, electromotive force	volt	V (W/A)
electric resistance	ohm	Ω (V/A)
electric capacitance	farad	F
magnetic flux	weber	Wb
inductance	henry	H
magnetic flux density	tesla	T (Wb/m^2)
magnetic field strength	ampere per metre	A/m
magnetomotive force	ampere	A
luminous flux	lumen	lm
luminance	candela per square metre	cd/m^2
illumination	lux	lx

* *Note* Nm^3 is the same as m^3 at normal temperature and pressure, i.e. 0°C and 760mm Hg (NTP or STP)

The litre is used instead of the cubic decimetre (1 litre = 1 dm^3) and is used in the welding industry to express the volume of a gas.

Pressure and stress may also be expressed in bar (b) or hectobar (hbar) instead of newton per square metre

Conversion factors from British units to SI units are given in Appendix 1.

1 metric tonne = 1000 kg.

Part 1

Welding science and technology

1

Welding science

Heat

Solids, liquids and gases: atomic structure

Substances such as copper, iron, oxygen and argon which cannot be broken down into any simpler substances are called elements; there are at the present time over 100 known elements. A substance which can be broken down into two or more elements is known as a compound.

An *atom* is the smallest particle of an element which can take part in a chemical reaction. It consists of a number of negatively charged particles termed electrons surrounding a massive positively charged centre termed the nucleus. Since like electric charges repel and unlike charges attract, the electrons experience an attraction due to the positive charge on the nucleus. Chemical compounds are composed of atoms, the nature of the compound depending upon the number, nature and arrangement of the atoms.

A molecule is the smallest part of a substance which can exist in the free state and yet exhibit all the properties of the substance. Molecules of elements such as copper, iron and aluminium contain only one atom and are monatomic. Molecules of oxygen, nitrogen and hydrogen contain two atoms and are diatomic. A molecule of a compound such as carbon dioxide contains three atoms and complicated compounds contain many atoms.

An atom is made up of three elementary particles: (1) protons, (2) electrons, (3) neutrons.

The *proton* is a positively charged particle and its charge is equal and opposite to the charge on an electron. It is a constituent of the nucleus of all atoms and the simplest nucleus is that of the hydrogen atom, which contains one proton.

The *electron* is 1/1836 of the mass of a proton and has a negative charge equal and opposite to the charge on the proton. The electrons form a cloud around the nucleus moving within the electric field of the positive charge and around which they are arranged in shells.

The *neutron* is a particle which carries no electric charge but has a mass equal to that of the proton and is a constituent of the nuclei of all atoms except hydrogen. The atomic number of an element indicates the number of protons in its nucleus and because an atom in its normal state exhibits no external charge, it is the same as the number of electrons in the shells.

Isotopes are forms of an element which differ in their atomic mass but not in some of their chemical properties. The atomic weight of an isotope is known as its mass number. For example, an atom of carbon has 6 protons and 6 neutrons in its nucleus so that its atomic number is 6. Other carbon atoms exist, however, which have 7 neutrons and 8 neutrons in the nucleus. These are termed isotopes and their mass numbers are 13 and 14 respectively, compared with 12 for the normal carbon atom. One isotope of hydrogen, called heavy hydrogen or deuterium, has a mass number 2 so that it has one proton and one neutron in its nucleus.

Electron shells. The classical laws of mechanics as expounded by Newton do not apply to the extremely minute world of the atom and the density, energy and position of the electrons in the shells are evaluated by quantum or wave mechanics. Since an atom in its normal state is electrically neutral, if it loses one or more electrons it is left positively charged and is known as a *positive ion*; if the atom gains one or more electrons it becomes a *negative ion*. It is the electrons which are displaced from their shells, the nucleus is unaffected, and if the electrons drift from shell to shell in an organized way in a completed circuit this constitutes an electric current.

In the *periodic classification*, the elements are arranged in order of their mass numbers, horizontal rows ending in the inert gases and vertical columns having families of related elements.

The lightest element, hydrogen, has one electron in an inner shell and the following element in the table, helium, has two electrons in the inner shell. This shell is now complete so that for lithium, which has three electrons, two occupy the inner shell and one is in the next outer shell. With succeeding elements this shell is filled with electrons until it is complete with the inert gas neon, which has two electrons in the inner shell and eight in the outer shell, ten electrons in all. Sodium has eleven electrons, two in the inner, eight in the second and one in a further outer shell. Electrons now fill this shell with succeeding elements until with argon it is temporarily filled with eight electrons so that argon has eighteen electrons in all. This is illustrated in Fig. 1.1 and this brief study will suffice to indicate how atoms of the elements differ from each other. Succeeding elements in the table have increasing numbers of electrons which fill more shells until the table is, at the present time, complete with just over 100 elements.

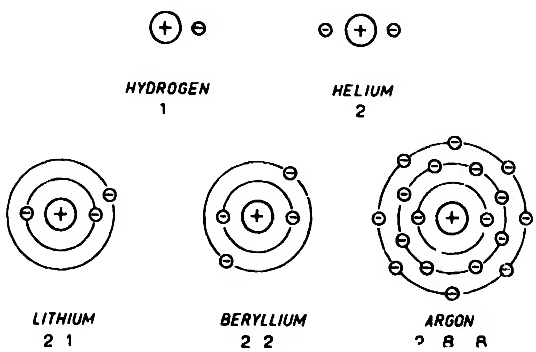
hydrogen	helium						
1	2						
lithium	beryllium	boron	carbon	nitrogen	oxygen	fluorine	neon
2	2	2	2	2	2	2	2
1	2	3	4	5	6	7	8
sodium	magnesium	aluminium	silicon	phosphorus	sulphur	chlorine	argon
2	2	2	2	2	2	2	2
8	8	8	8	8	8	8	8

The shells are then filled up thus:

2	8.				
2	8	8.			
2	8	18.			
2	8	18	8.		
2	8	18	18.		
2	8	18	18	8.	
2	8	18	32	18.	
2	8	18	32	18	8.

The electrons in their shells possess a level of energy and with any change in this energy light is given out or absorbed. The elements with completed or temporarily completed shells are the inactive or inert gases helium, neon, argon, xenon and radon, whereas when a shell is nearly complete (oxygen, fluorine) or has only one or two electrons in a shell (sodium, magnesium), the element is very reactive, so that the characteristics of an element are greatly influenced by its electron structure. When a metal filament such as tungsten is heated in a vacuum it emits electrons, and if a positively charged plate (anode) with an aperture in it is put in front near the filament, the electrons stream through the aperture attracted by the positive charge and form an electron beam. This beam can be focused and guided and is used in the television tube, while a beam of higher energy can be used for welding by the electron beam process (see pp. 579–81).

Fig 1.1



If the atoms in a substance are not grouped in any definite pattern the substance is said to be amorphous, while if the pattern is definite the substance is crystalline. Solids owe their rigidity to the fact that the atoms are closely packed in geometrical patterns called space lattices which, in metals, are usually a simple pattern such as a cube. The positions which atoms occupy to make up a lattice can be observed by X-rays.

Atoms vibrate about their mean position in the lattice, and when a solid is heated the heat energy supplied increases the energy of vibration of the atoms until their mutual attraction can no longer hold them in position in the lattice so that the lattice collapses, the solid melts and turns into a liquid which is amorphous. If we continue heating the liquid, the energy of the atoms increases until those having the greatest energy and thus velocity, and lying near the surface, escape from the attraction of neighbouring atoms and become a vapour or gas. Eventually when the vapour pressure of the liquid equals atmospheric pressure (or the pressure above the liquid) the atoms escape wholesale throughout the mass of the liquid which changes into a gaseous state and the liquid boils.

Suppose we now enclose the gas in a closed vessel and continue heating. The atoms are receiving more energy and their velocity continues to increase so that they will bombard the walls of the vessel, causing the pressure in the vessel to increase.

Atoms are grouped into molecules, which may be defined as the smallest particles which can exist freely and yet exhibit the chemical properties of the original substance. If an atom of sulphur, two atoms of hydrogen, and four atoms of oxygen combine, they form a molecule of sulphuric acid. The molecule is the smallest particle of the acid which can exist, since if we split it up we are back to the original atoms which combined to form it.

From the foregoing, it can be seen that the three states of matter – solids, liquids and gases – are very closely related, and that by giving or taking away heat we can change from one state to the other. Ice, water and steam give an everyday example of this change of state.

Metals require considerable heat to liquefy or melt them, as for example, the large furnaces necessary to melt iron and steel.

We see examples of metals in the gaseous state when certain metals are heated in the flame. The flame becomes coloured by the gas of the metal, giving it a characteristic colour, and this colour indicates what metal is being heated. For example, sodium gives a yellow coloration and copper a green coloration.

This change of state is of great importance to the welder, since he is concerned with the joining together of metals in the liquid state (termed

fusion welding) and he has to supply the heat to cause the solid metal to be converted into the liquid state to obtain correct fusion.

Temperature:* thermometers and pyrometers

The temperature of a body determines whether it will give heat to, or receive heat from, its surroundings.

Our sense of determining hotness by touch is extremely inaccurate, since iron will always feel colder than wood, for example, even when actually at the same temperature.

Instruments to measure temperature are termed thermometers and pyrometers. Thermometers measure comparatively low temperatures, while pyrometers are used for measuring the high temperatures as, for example, in the melting of metals.

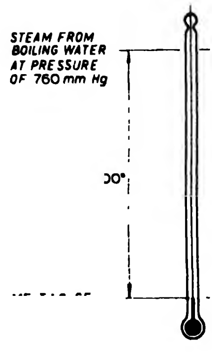
In the thermometer, use is made of the fact that some liquids expand by a great amount when heated. Mercury and alcohol are the usual liquids used. Mercury boils at 375°C and thus can be used for measuring temperatures up to about 330°C.

Mercury is contained in a glass bulb which connects into a very fine bore glass tube called a capillary tube and up which the liquid expands (Fig. 1.2).

The whole is exhausted of air and sealed off. The fixed points on a thermometer are taken as the melting point of ice and the steam from pure water at boiling point at standard pressure (760 mm mercury).

In the Celsius or Centigrade thermometer the freezing point is marked 0 and boiling point 100; thus there are 100 divisions, called degrees and shown thus °. The Kelvin scale (K) has its zero at the absolute zero of temperature, which is − 273.16°C. To convert approximately from °C to K add 273 to the Celsius figure.

Fig. 1 2 Celsius or Centigrade graduations



Kelvin scale of temperature This scale of absolute temperature is a thermodynamic temperature scale based on the efficiency of a reversible heat engine If the reversible cycles are performed at various points on the scale, the amounts of work done on each cycle are equal The scale is compared with the gas scale of temperature by choosing the degree size and defining the absolute zero Kelvin (K) as − 273 16 °C

To measure temperatures higher than those measurable with an ordinary thermometer we can employ:

(1) Temperature cones.
(2) Temperature-indicating paints or crayons.
(3) Pyrometers:
  (*a*) Electrical resistance.
  (*b*) Thermo-electric.
  (*c*) Radiation.
  (*d*) Optical.

(1) Temperature cones (Seger cones) are triangular pyramids made of a mixture of china clay, lime, quartz, iron oxide, magnesia, and boric acid in varying proportions so that they melt at different temperatures and can be used to measure temperatures between 600 °C and 2000 °C. They are numbered according to their melting points and are generally used in threes, numbered consecutively, of approximately the temperature required. When the temperature reaches that of the lowest melting point cone it bends over until its apex touches the floor. The next cone bends slightly out of the vertical while the third cone remains unaffected. The temperature of the furnace is that of the cone which has melted over.

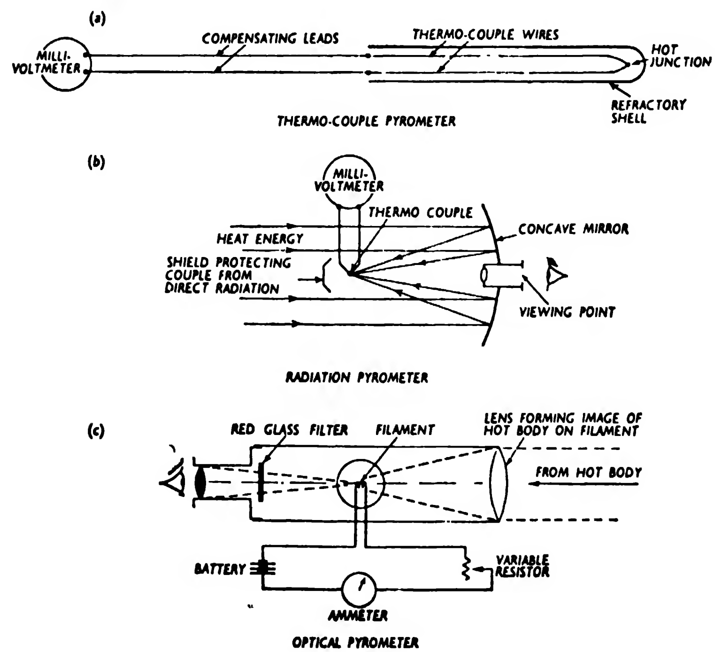
(2) Temperature-indicating paints and crayons either melt or change colour or appearance at definite temperatures. Temperature indicators are available as crayons (sticks), pellets or in liquid form and operate on the melting principle and not colour change. They are available in a range from 30 °C to 1650 °C and each crayon has a calibrated melting point. To use the crayon, one of the temperature range required is stroked on the work as the temperature rises and leaves a dry opaque mark until at the calibrated temperature it leaves a liquid smear which on cooling solidifies to a translucent or transparent appearance. Up to 700 °C a mark can be made on the work piece before heating and liquefies at the temperature of the stick. Similarly a pellet of the required temperature is placed on the work and melts at the appropriate temperature while the liquid is sprayed on to the surface such as polished metal (or glass) which is difficult to mark with a crayon, and dries to a dull opaque appearance. It liquefies sharply at its calibrated temperature and remains glossy and transparent upon cooling.

(3) Pyrometers. (*a*) Electrical resistance pyrometers. Pure metals increase in resistance fairly uniformly as the temperature increases. A platinum wire is wound on a mica former and is placed in a refractory sheath, and the unit placed in the furnace. The resistance of the platinum wire is measured (in a Wheatstone's bridge network) by passing a current through it. As the temperature of the furnace increases the resistance of the platinum

increases and this increase is measured and the temperature read from a chart.

(*b*) Thermo-electric (thermo-couple) pyrometers. When two dissimilar metals are connected together at each end and one pair (or junction) of ends is heated while the other pair is kept cold, an electromotive force (e.m.f.) or voltage is set up in the circuit (Peltier Effect). The magnitude of this e.m.f. depends upon (*a*) the metals used and (*b*) the difference in temperature between the hot and cold junctions. In practice the hot junction is placed in a refractory sheath while the other ends (the cold junction) are connected usually by means of compensating leads to a millivoltmeter which measures the e.m.f. produced in the circuit and which is calibrated to read the temperature directly on its scale. The temperature of the cold junction must be kept steady and since this is difficult, compensating leads are used. These are made of wires having the same thermo-electric characteristics as those of the thermo-couple but are much cheaper and they get rid of the thermo-electric effect of the junction between the thermo-couple wires and the leads to the millivoltmeter, when the temperature of the cold junction varies. The couples generally used are copper/constantan (60 % Cu, 40 % Ni) used up to 300 °C; chromel (90 % Ni, 10 % Cr)/alumel (95 % Ni, 3 % Mn, 2 % Al) up to 1200 °C; and platinum/platinum–rhodium (10 % Rh) up to 1500 °C (Fig. 1.3*a*).

Fig. 1.3



(*c*) Radiation pyrometers. These pyrometers measure the radiation emitted from a hot body. A 'black body' surface is one that absorbs all radiation falling upon it and reflects none, and conversely will emit all radiations. For a body of this kind, E, the heat energy radiated, is proportional to the fourth power of the absolute temperature, i.e. $E \propto T^4$ (Stefan–Boltzmann Law) so that $E = kT^4$. If a body is however radiating heat in the open, the ratio of the heat which it radiates to the heat that a black body would radiate at the same temperature is termed the emissivity, e, and this varies with the nature, colour and temperature of the body. Knowing the emissivity of a substance we can calculate the true temperature of it when radiating heat in the open from the equation:

$$(\text{True temperature})^4 = \frac{(\text{Apparent temperature})^4}{\text{emissivity}}$$

(temperatures are on the absolute scale).

In an actual radiation pyrometer the radiated heat from the hot source is focussed on to a thermo-couple by means of a mirror (the focussing can be either fixed or adjustable) and the image of the hot body must cover the whole of the thermo-couple. The e.m.f. generated in the thermo-couple circuit is measured as previously described on a millivoltmeter (Fig. 1.3*b*).

(*d*) Optical pyrometers. The disappearing filament type is an example of this class of pyrometer. A filament contained in an evacuated bulb like an electric light bulb is viewed against the hot body as a background. By means of a control resistor the colour of the filament can be varied by varying the current passing through it until the filament can no longer be seen, hot body and filament then being at the same temperature. An ammeter measures the current taken by the filament and can be calibrated to read the temperature of the filament directly.

The judging of temperatures by colour is usually very inaccurate. If steel is heated, it undergoes a colour change varying from dull red to brilliant white. After considerable experience it is possible to estimate roughly the temperature by this means, but no reliance can be placed on it (Fig. 1.3*c*).

Temperature gradient and heat affected zone

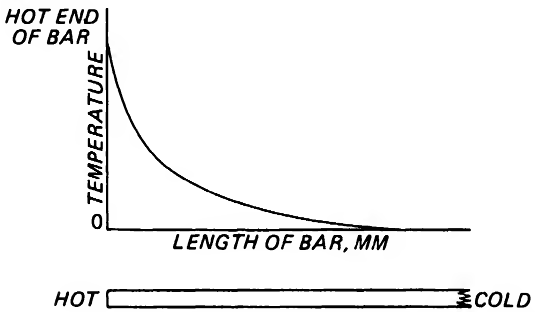
The gradient is the rate of change of a quantity with distance so that the temperature gradient along a metal bar is the rate of change of temperature along the bar.

This can be illustrated by Fig. 1.4*a*, which shows the graph of temperature plotted against distance for a bar heated at one end, the other end being cold. The hot portion loses heat by conduction, convection and

radiation. The conduction of heat along the bar will be greater the better the thermal conductivity of the metal of the bar so that heat travels more quickly along a copper bar than along a steel bar, and the graph shows that the hot end is losing heat to its surroundings much more quickly than the colder parts of the bar. The greater the difference of temperature between two points, the more rapidly is the heat lost.

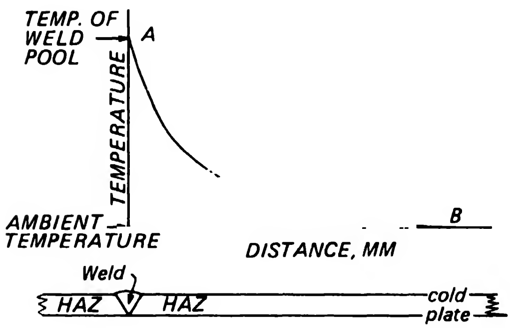
If two steel plates are welded together, Fig. 1.4*b* shows the temperature gradient from the molten pool to the cold parent plate on each side of the weld. The gradient on one side only is shown in the figure. That portion of

Fig. 1 4



TEMPERATURE GRADIENT ALONG BAR HEATED AT ONE END

(*a*)



TEMPERATURE GRADIENT AND HAZ FOR A BUTT WELD BETWEEN TWO PLATES (ONE SIDE ONLY SHOWN)

(*b*)

HEAT DISSIPATION BY CONDUCTION

(*c*)

the plate on either side of the weld, affected by the heat and in which the metal suffers thermal disturbance, is known as the Heat-Affected Zone (HAZ) and the areas nearest the weld in which this disturbance is greatest undergo a change in structure which may include recrystallization, refining and grain growth (q.v.). The larger and thicker the plate the more quickly will the molten pool lose heat (or freeze) by conduction and for this reason an arc should never be struck briefly on a thick section cold plate especially in certain steels as the sudden quenching effect may lead to cracking.

Fig. 1.4*c* shows that a butt weld loses heat by conduction in two directions while in a fillet joint the heat has three directions of travel. Both joints also lose heat by convection and radiation.

Expansion and contraction

When a solid is heated, the atoms of which it is composed vibrate about their mean position in the lattice more and more. This causes them to take up more room and thus the solid expands.

Most substances expand when heated and contract again when cooled, as the atoms settle back into their normal state of vibration.

Metals expand by a much greater amount than other solid substances, and there are many practical examples of this expansion in everyday life.

Gaps are left between lengths of railway lines, since they expand and contract with atmospheric temperature changes. Fig. 1.5*a* shows the expansion joint used by British Rail. With modern methods of track construction only the last 100 m of rail is allowed to expand or contract longitudinally irrespective of the total continuous length of welded rail, and this movement is well within the capacity of the expansion joint or adjustment switch.

Iron tyres are made smaller than the wheel they are to fit. They are heated and expand to the size of the wheel and are fitted when hot. On being quickly cooled, they contract and grip the wheel firmly.

Large bridges are mounted on rollers fitted on the supporting pillars to allow the bridge to expand.

In welding, this expansion and contraction is of the greatest importance. Suppose we have two pieces of steel bar about 1 m long. If these are set together at an angle of 90°, as shown, and then welded and allowed to cool, we find that they have curled or bent up in the direction of the weld (Fig. 1.5*b* and *c*).

The hot weld metal, on contracting, has caused the bar to bend up as shown, and it is evident that considerable force has been exerted to do this.

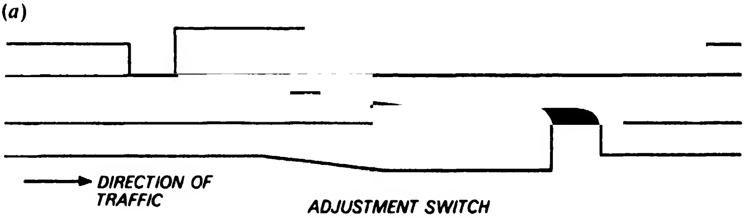
A well-known example of the use to which these forces, exerted during expansion and contraction, are put is the use of iron bars to pull in or strengthen defective walls of buildings.

Plates or S pieces are placed on the threaded ends of the bar, which projects through the walls which need pulling in. The bar is heated to redness and nuts on each end are drawn up tight against the plates on the walls. As the bar cools, gradually the walls are pulled in.

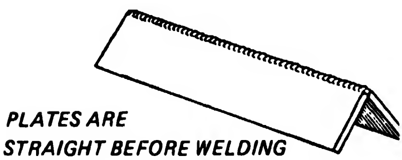
Different metals expand by different amounts. This may be shown by riveting together a bar of copper and a bar of iron about 0.5 m long and 25 mm wide. If this straight composite bar is heated it will become bent, with the copper on the outside of the bend, showing that the copper expands more than the iron (Fig. 1.6). This composite bar is known as a bi-metal strip and is used in engineering for automatic control of temperature.

Fig. 1.5

(*a*)



(*b*)



(*c*)

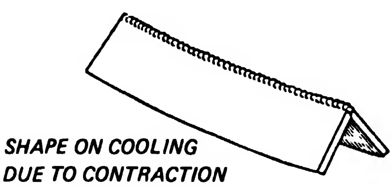
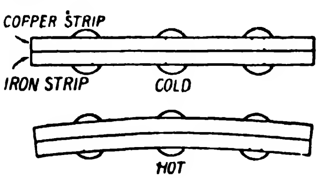


Fig. 1.6



Coefficient of linear expansion

The fraction of its length which a bar will expand when heated through one degree rise in temperature is termed its *coefficient of linear expansion.* (This also applies to contraction when the bar is cooled.) This fraction is very small; for example, for iron it is

$$\frac{12}{1\,000\,000}$$

That is, a bar of iron length l would expand by $l \times \frac{12}{1\,000\,000}$ for every degree rise in temperature. Hence, if the rise was $t°$, the expansion would be $\frac{12}{1\,000\,000} \times l \times t$.

The fraction $\frac{12}{1\,000\,000}$ is usually denoted by the letter a. Thus the increase in length of a bar of original length l, made of material whose coefficient of linear expansion is a, when heated through $t°$ is lat.

Thus, the final length of a bar when heated equals its original length plus its expansion, that is:

$$L = l + lat$$

Final length = original length + expansion.

This can also be written: $L = l\,(1 + at)$.

Length after being heated through t°C

Example

Given that the coefficient of linear expansion of copper is $\frac{17}{1\,000\,000}$ or 0.000 017 per degree C, find the final length of a bar of copper whose original length was 75 mm, when heated through 50°C.

Final length = original length + expansion, i.e.:

$$\text{Final length} = 75 + \left(75 \times \frac{17}{1\,000\,000} \times 50\right)$$

$$= 75 + \frac{63\,750}{1\,000\,000} = 75 + \frac{6375}{100\,000} = 75.06 \text{ mm.}$$

The above is equally true for calculating the contraction of a bar when cooled.

Table of coefficients of linear expansion of metals per degree C

Metal	a	Metal	a
Lead	0.000 027	Zinc	0.000 026
Tin	0.000 021	Cast iron	0.000 010
Aluminium	0.000 025	Nickel	0.000 013
Copper	0.000 017	Wrought iron	0.000 012
Brass 60% copper, 40% zinc	0.000 020	Mild steel	0.000 012

Invar, a nickel–steel alloy containing 36% nickel, has a coefficient of linear expansion of only 0.000 000 9, that is, only $\frac{1}{13}$ of that of mild steel, and thus we can say that invar has practically no expansion when heated.

The expansion and contraction of metal is of great importance to the welder, because, as we have previously shown, large forces or stresses are called into play when it takes place. If the metal that is being welded is fairly elastic, it will stretch, or give, to these forces, and this is a great help, although stresses may be set up as a result in the welded metal. Some metals, however, like cast iron, are very brittle and will snap rather than give or show any elasticity when any force is applied. As a result, the greatest care has to be taken in applying heat to cast iron and in welding it lest we introduce into the metal, when expanding and contracting, any forces which will cause it to break. This will be again discussed at a later stage.

Coefficient of cubical expansion

If we imagine a solid being heated, it is evident that its volume will increase, because each side undergoes linear expansion.

A cube, for example, has three dimensions, and each will expand according to the previous rule for linear expansion. Suppose each face of the cube was originally length l and finally length L after being heated through t°C. Let the coefficient of linear expansion be a per degree C.

The original volume was $l \times l \times l = l^3$.

Each edge will have expanded, and for each edge we have:

Final length $L = l\,(1 + at)$ as before (Fig. 1.7).

Thus the new volume $= l(1 + at) \times l(1 + at) \times l(1 + at)$
$= l^3(1 + 3at)$ approximately.

Thus, the final volume = original volume $(1 + 3at)$.

That is, the *coefficient of cubical expansion* may be taken as being three times the coefficient of linear expansion.

Example

A brass cube has a volume of 0.006 m^3 (6×10^6 mm^3) and is heated through a 65 °C rise in temperature. Find its final volume, given that the coefficient of linear expansion of brass = 0.000 02 per degree C.

$$\begin{aligned}\text{Final volume} &= \text{original volume } (1 + 3at)\\ V &= 0.006(1 + 3 \times 0.00002 \times 65)\\ &= 0.006(1.0039)\\ &= 0.0060234\,\text{m}^3.\end{aligned}$$

The joule and the newton

Heat is a form of energy and the unit of energy is the joule (J). A joule may be defined as the energy expended when a force of 1 newton (N) moves through a distance of 1 metre (m). (Note: a newton is that force which, acting on a mass of 1 kilogram (kg), gives it an acceleration of 1 metre per second per second (1 m/s^2). The gravitational force on a mass of 1 kg equals 9.81 N so that for practical purposes, to convert from kilograms force to newtons, multiply by 10.)

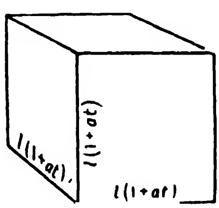
Specific heat capacity

The specific heat capacity is defined as the quantity of heat required to raise unit mass of a substance through 1° rise in temperature. The SI unit is in kilojoules per kilogram K (kJ/kg K, symbol c). Note that since K adds 273 to °C, a rise in temperature will be the same in K or °C.

Example

Find the heat gained by a mass of 20 kg of cast iron which is raised through a temperature of 30 °C, given that the specific heat capacity of cast iron is 0.55 kJ/kg K.

Fig. 1.7



Heat gained = mass × c × rise in temperature
= 20 × 0.55 × 30 kilojoules
= 330 kJ.

Substance	Specific heat capacity	Substance	Specific heat capacity
Water	4.2×10^3	Mild steel	0.45×10^3
Aluminium	0.91×10^3	Wrought iron	0.47×10^3
Tin	0.24×10^3	Zinc	0.4×10^3
Lead	0.13×10^3	Cast iron	0.55×10^3
Copper	0.39×10^3	Nickel	0.46×10^3
Brass	0.38×10^3		

The above values are approximately 4.2×10^3 as great as the values when specific heat capacities were expressed in calories per gram degree C.

Melting point

The melting point of a substance is the temperature at which the change of state from solid to liquid occurs, and this is usually the same temperature at which the liquid will change back to solid form or freeze.

Substances which expand on solidifying have their freezing point lowered by increase of pressure while others which contract on freezing have their freezing point raised by pressure increase.

The melting point of a solid with a fairly low melting point can be determined by attaching a small glass tube, with open end containing some of the solid, to the bulb of a thermometer. The thermometer is then placed in a container holding a liquid, whose boiling point is above the melting point of the solid, and fitted with a cover, as shown in Fig. 1.8, and a stirrer is also included. The container is heated and the temperature at which the solid melts is observed. The apparatus is now allowed to cool and the temperature at which the substance solidifies is noted. The mean of these two readings gives the melting point of the solid. By using mercury, which boils at 357 °C, as the liquid in the container, the melting point of solids which melt between 100 and 300 °C could be obtained.

Determination of the melting point by method of cooling

The solid, of which the melting point is required, is placed in a suitable container, fitted with a cork or stopper through which a thermometer is inserted (Fig. 1.9). A hole in the stopper prevents pressure rise. The container is heated until the solid melts, and heating is continued until the temperature is raised well above this point. The liquid is now allowed to cool and solidify and the temperature is taken every quarter or

Fig. 1.8

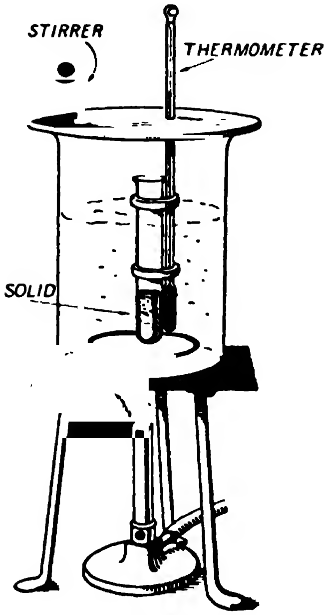
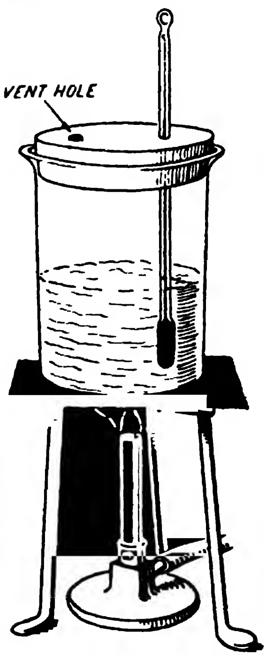


Fig. 1.9



half minute. This temperature is plotted on a graph against the time, and the shape of the graph should be as shown in Fig. 1.10.

If the melting point of a metal is required, the metal is placed in a fireclay or graphite crucible and heated by means of a furnace, and the temperature is measured, at the same intervals, by a pyrometer. The metal, on cooling, begins to solidify and form crystals in exactly the same way as any other solid. The portion *A* shows the fall in temperature of the liquid or molten metal. The portion *B* indicates the steady temperature while solidification is taking place, and portion *C* shows the further fall in temperature as the solid loses heat. The temperature t° of the portion *B* of the curve is the melting point of the solid.

In practice we may find that the temperature falls below the dotted line, as shown, that is, below the solidifying temperature. This is due to the difficulty which the liquid may experience in commencing to form crystals, and is called 'super-cooling'. It then rises again to the true solidifying point and cooling then takes place as before (Fig. 1.11).

This method of determination of the melting point is much used in finding the melting point of alloys and in observing the behaviour of the constituents of the alloys when melting and solidifying.

The melting point of a metal is of great importance in welding, since,

Fig. 1.10

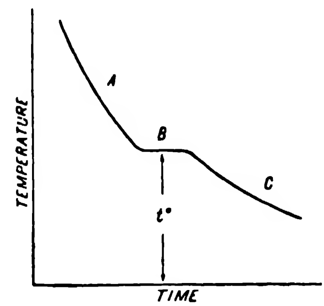
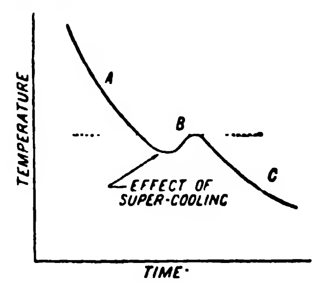


Fig. 1.11



together with the capacity for heat of the metal, it determines how much heat is necessary for fusion. The addition of other substances or metals to a given metal (thus forming an alloy) will affect its melting point.

Specific latent heat

If a block of ice is placed in a vessel with a thermometer and heat is applied, the temperature remains steady at 0 °C (273 K) until the whole of the ice has been melted and then the temperature begins to rise. The heat given to the ice has not caused any rise in temperature but a change of state from solid to liquid and is called the specific latent heat of fusion. When the change of state is from liquid to gas it is termed the specific latent heat of vaporization (or evaporation) and is expressed in joules or kilojoules (kJ) per kilogram (J/kg or kJ/kg).

Specific latent heat of fusion in kJ/kg

Aluminium	393	Nickel	273
Copper	180	Tin	58
Iron	205	Ice	333

Specific latent heat of fusion is more important in welding than specific latent heat of vaporization, because a comparison of these figures gives an indication of the relative amounts of heat required to change the solid metal into the liquid state before fusion.

Since the heat must be given to a solid to convert it to a liquid, it follows that heat will be given out by a liquid when solidifying. This has already been demonstrated when determining the melting point of a liquid by the method of cooling. When the change of state from liquid to solid takes place (*B* on the curve in Fig. 1.10) heat is given out and the temperature remains steady until solidification is complete, when it again begins to fall.

Transfer of heat

Heat can be transferred in three ways: conduction, convection, radiation.

Conduction. If the end of a short piece of metal rod is heated in a flame, it rapidly gets too hot to hold (Fig. 1.12). Heat has been transferred by conduction from atom to atom through the metal from the flame to the hand. If a rod of copper and one of steel are placed in the flame, the copper rod gets hotter more quickly than the steel one, showing that the heat has

been conducted by the copper more quickly than the steel. If the rods are held in a cork and the cork gripped in the hand, they can now be held comfortably. The cork is a bad conductor of heat. All metals are good conductors but some are better than others, and the rate at which heat is conducted is termed the *thermal conductivity* and is measured in watts per metre degree (W/m °C).

The conductivity depends on the purity of the metal, its structure and the temperature.

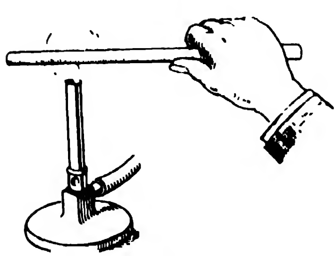
As the temperature rises the conductivity decreases and impurities in a metal greatly reduce the conductivity.

The thermal conductivity is closely allied to the electrical conductivity, that is, the ease with which an electric current is carried by a metal. It is interesting to compare the second and third columns in the table. From these we see that in general the better a metal conducts heat, the better it conducts electricity.

Table of comparative conductivities (taking copper as 100)

	Thermal conductivity	Electrical conductivity
Silver	106	108
Copper	100	100
Aluminium	62	56
Zinc	29	29
Nickel	25	15
Iron	17	17
Steel	13–17	13–17
Tin	15	17
Lead	8	9

Fig. 1.12



The effect of conductivity of heat on welding practice can clearly be seen from the calculations in Fig. 1.13, where a block of copper and one of steel of equal mass are to be welded. It is seen that if the two blocks were to be each brought up throughout their mass to melting point, the steel would take *a much greater quantity of heat* than the copper would.

When the heat is applied at one spot, copper being such a good conductor, heat is rapidly transferred from this spot throughout its mass, and we find that the spot where the heat is applied will not melt until the whole mass of the copper has been raised to a very high temperature indeed.

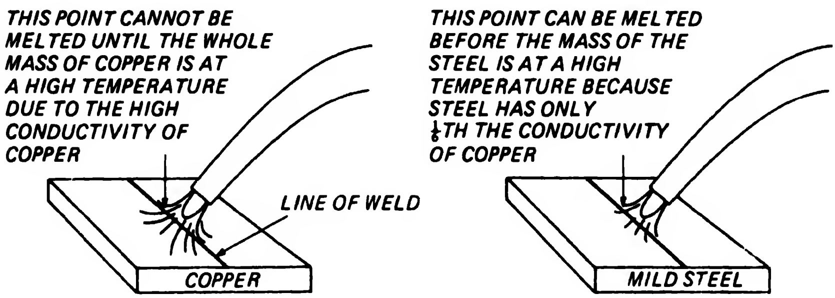
With the mild steel block, on the other hand, the heat conductivity is only about $\frac{1}{6}$ (from the table) that of the copper, that is, the heat is conducted away at only $\frac{1}{6}$ the rate. Hence we find that the spot where the heat is applied will be raised to melting point long before the rest of the block has become very hot.

Because of this high conductivity of copper, it is usual to employ greater heat than when welding the same thickness of steel or iron.

For this reason also, when welding copper, whether by arc or oxy-acetylene, it is always advisable to heat the work up to a high temperature over a large area around the area to be welded. In this way the heat will not be conducted to colder regions so rapidly and better fusion in the weld itself can be obtained.

Cast iron is a comparatively poor conductor of heat compared with

Fig. 1.13



Mass 1 kg
Melting point of copper 1083 °C
Specific heat capacity 0.39 x 10^3 J/kg °C
Heat required to raise copper to melting point
= 1 x 1083 x 0.39 x 10^3 J
= 422 370 J
= 0.422 x 10^6 J.

Mass 1 kg
Melting point of steel 1400 °C
Specific heat capacity 0.45 x 10^3 J/kg °C
Heat required to raise steel to melting point
= 1 x 1400 x 0.45 x 10^3 J
= 630 000 J
= 0.63 x 10^6 J.

copper. If we heat a casting in one spot, therefore, heat will only be transferred away slowly. The part being heated thus expands more quickly than the surrounding parts and, since expansion is irregular, great forces, as before explained, are set up and, since cast iron is brittle and has very small elasticity, the casting fractures. The welding of cast iron is thus a study of expansion and contraction and conduction of heat and, to weld cast iron successfully, care must be taken that the temperature of the whole casting is raised and lowered equally throughout its mass. This will be discussed at a later stage.

Convection. When heat is transferred from one place to another by the motion of heated particles, this is termed convection. For example, in the hot water system of a house, heat from the fire heats the water and hot water, being less dense than colder water, rises in the pipes, forming convection currents and transferring heat to the storage tank.

In the heat treatment of steel it is often necessary to cool the steel slightly more quickly than if it cooled naturally, in order to harden it. It is cooled, therefore, in an air blast, the heat being transferred thus by convection.

Radiation. Heat is transferred by radiation as pulses of energy, termed quanta, through the intervening space. We sit in front of a fire and it feels warm. There is no physical contact between our bodies and the fire. The heat is being transferred by radiation. Heat transferred in this manner travels according to the laws of light and is reflected and bent in the same way.

The sun's heat is transmitted by radiation to our planet but the method by which the heat travels through space is not fully understood. Metal, if allowed to cool in a still atmosphere, loses its heat by radiation and any other bodies in the neighbourhood will become warmed.

It is evident that the outside of the hot metal will lose heat more quickly than the interior, and we find, for example, that the surface of cast iron is much harder than below the surface, because it has lost heat more quickly.

Chills are strips or blocks of metal placed adjacent to the line of weld during the welding operation in order to dissipate heat and reduce the area affected by the input of heat, the heat-affected zone (HAZ). Heat is removed by conduction, convection and radiation, and copper is often used because of its good heat conducting properties. Heat control can be effected by moving the chills nearer or further from the weld.

Behaviour of metals under loads

Stress, strain and elasticity

When a force, or load, is applied to a solid body it tends to alter the shape of the body, or deform it.

The atoms of the body, owing to their great attraction for each other, resist, up to a certain point, the attempt to alter their position and there is only a slight distortion of the crystal lattice.

If the applied force is removed before this point is reached, the body will regain its original shape.

This property, which most substances possess, of regaining their original shape upon removal of the applied load is termed *elasticity*.

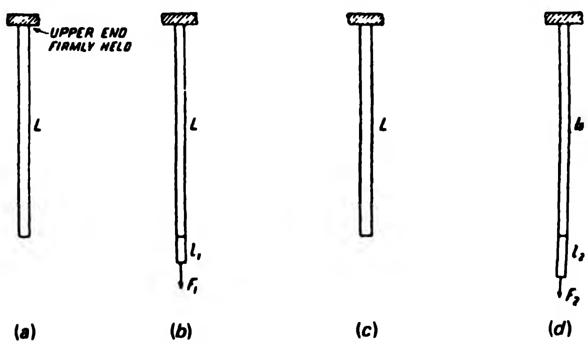
Should the applied load be large enough, however, the resistance of the atoms will be overcome and they will move and take up new positions in the lattice. If the load is now removed, the body will no longer return to its former shape. It has become permanently distorted (Fig. 1.14).

The point at which a body ceases to be elastic and becomes permanently distorted or set is termed the yield point, and the load which is applied to cause this is the yield-point load. The body is then said to have undergone plastic deformation or flow.

Whenever a change of dimensions of a body occurs, from whatever cause, a state of *strain* is set up in that body. Strain is usually measured (for calculation purposes) by the ratio or fraction:

$$\frac{\text{change of dimensions in direction of applied load}}{\text{original dimensions in that direction}}$$

Fig. 1.14 (*a*) Original length of specimen. (*b*) Extension produced = l_1. Elastic limit not reached. F_1 = applied force. (*c*) Force removed, specimen recovers its original dimensions. (*d*) Extension produced = l_2. Elastic limit exceeded by application of force. Specimen now remains permanently distorted or set, and does not recover its original dimensions when force is removed. F_2 = applied force.



Example

A bar is 100 mm long and is stretched $\frac{1}{4}$ mm by an applied load along its length. Find the strain.

$$\text{Strain} = \frac{\text{change in length}}{\text{original length}} = \frac{\frac{1}{4}}{100} = \frac{1}{400}.$$

The magnitude of the force or load on unit area of cross-section of the body producing the strain is termed the *stress*.

Stress = force or load per unit area.

Hooke's Law states that for an elastic body strain is proportional to stress.

The mass of a body is the quantity of matter which it contains, so that it is dependent upon the number of atoms in its structure. Mass is measured in kilograms (kg) and 1000 grams (g) equal 1 kg. Note 1 lb = 0.4536 kg and 1 kg = 2.2 lb. Newton's Universal Law of Gravitation states that every particle of matter attracts every other particle of matter with a force (F) which is proportional to the product of the masses (m_1 and m_2) of the two particles and inversely proportional to the square of the distance (d) between them, $F \propto m_1 m_2/d^2$. The weight of a body is the force by which it is attracted to the earth (the force of gravity), but because the earth is a flattened sphere, this force and hence the weight of the body vary somewhat according to its position on the earth's surface. On the surface of the moon, which has about one-sixth of the mass of the earth, a mass of one kilogram would weigh about one-sixth of a kilogram. To distinguish a mass of one kilogram from a force of one kilogram, which is the force of attraction due to the gravitational pull of the earth, the letter *f* is added thus, kgf.

The unit of force termed the newton avoids the distinction between mass and weight and is defined as 'that force which will give an acceleration of 1 metre per second per second to a mass of 1 kilogram'.

Units of stress or pressure

The following multiples of units are used:

tera- (T) = one million million	10^{12}
giga- (G) = one thousand million	10^9
mega- (M) = one million	10^6
kilo- (k) = one thousand	10^3
hecto- (h) = one hundred	10^2.

The SI unit of stress or pressure is the newton per square metre (N/m^2) which is also known as the pascal (Pa), and 1 N/m^2 = 1 Pa. This is a small unit and when using it to express tensile strengths of materials large

numbers are involved with the use of the meganewton per square metre (MN/m^2) or megapascal (MPa).

If, however, the newton per square millimetre (N/mm^2) is used, as in this book, large figures are avoided and the change to the SI unit is easily made since 1 N/mm^2 = 1 MN/m^2 or 1 MPa.

The bar (b) and its multiple the hectobar (hbar) are also used as units of pressure and stress. 1 bar is equal to the pressure of a vertical column of mercury 750 mm high and for conversion purposes it can be taken to equal 15 lbf* per square inch. It should be noted that 1 bar = 10^5 N/m^2 or 10^5 Pa, and 1 hbar = 10 N/mm^2.

Gauges for cylinders of compressed gases can be calibrated in bar, a cylinder pressure of 2500 lbf/in^2 being 172 bar.

Tensile strength can be expressed in hbar. A specimen of aluminium may have a tensile strength of 12 hbar which is equal to 120 N/mm^2.

If stress is stated in $tonf/in^2$ or kgf/mm^2 the following conversions can be used. (A full list of conversion factors is given in the appendix.)

$Tonf/in^2$ to MN/m^2 or N/mm^2, multiply by 15.5; MN/m^2 or N/mm^2 to $tonf/in^2$, multiply by 0.0647; kgf/m^2 to N/m^2, multiply by 9.8; and approximately 1 hbar = 1 kgf/mm^2.

If a stress is applied to a body and it changes its shape within its elastic limits, the ratio stress/strain is termed the modulus of elasticity or Young's modulus (E) of the material. The unit is N/m^2 or Pa, and a typical value for a specimen of aluminium is 69×10^3 MN/m^2 or MPa or N/mm^2.

There are three kinds of simple stress: (1) tensile, (2) compression, (3) shear.

Tensile stress

If one end of a metal rod is fixed firmly and a force is applied to the other end to pull the rod, it stretches. A tensile force has been applied to the rod and when it is measured on unit cross-sectional area it is termed a tensile stress.

Example

A force of 0.5 MN is applied so as to stretch a bar of cross-sectional area 400 mm^2. Find the tensile stress

$$\text{Tensile stress} = \frac{\text{load}}{\text{area of cross-section}} = \frac{500\,000}{400} = 1250 \text{ N/mm}^2.$$

* 1 bar = 14 508 lbf/in^2
1 lbf/in^2 = 0.0689 bar.

A machine known as a tensile strength testing machine, which will be described later (Chapter 5), is used for determining the tensile strength of materials and welded joints.

The specimen under test is clamped between two sets of jaws, one fixed and one moving, and the force can be increased until the specimen breaks.

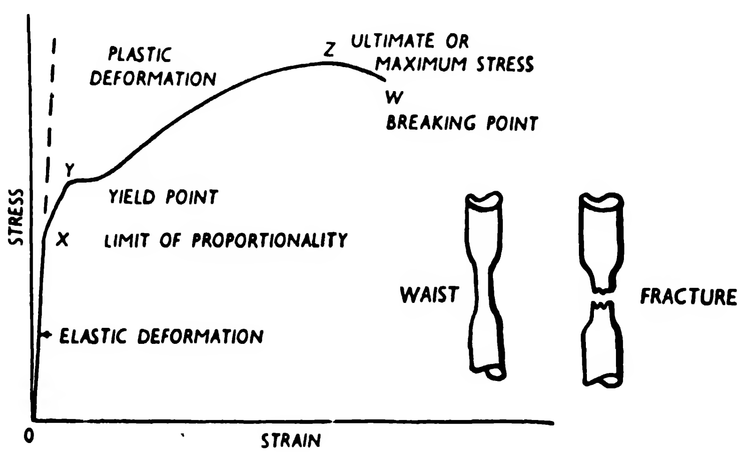
Suppose a piece of mild steel is placed in the machine. As the tensile stress is increased, the bar becomes only very slightly longer for each increase of force. Then a point is reached when, for a very small increase of force, the bar becomes much longer. This is the yield point and the bar has been stretched beyond its elastic limit, and is now deforming plastically.

If the applied load had been reduced before this point was reached, the bar would have recovered its normal size, but will not do so when the yield point has been passed.

As the load is increased beyond the yield point the elongation of the bar for the same increase of loading becomes much greater, until a point is reached when the bar begins to get reduced in cross-sectional area and forms a waist, as shown. Less load is now required to extend the bar, since the load is now applied on a smaller area, the waist becomes smaller and the bar breaks. The accompanying diagram (Fig. 1.15) will make this clear.

When the stress is first applied, the extension of the bar is very small and needs accurate measurement, but it is proportional to the load so that the graph of stress/strain is a straight line. At one point X the graph deviates a little from the straight line OX, so that after X the strain is no longer proportional to the stress. The point X is the *limit of proportionality* and Hooke's Law is no longer obeyed. At Y the extension suddenly becomes

Fig 1.15 Stress–strain diagram, mild steel.



much greater than before for an equal increase in load and Y is termed the yield point, the stress at this point being the yield-point stress.

Increase of load produces progressive increase of length to the point Z. At this point the waist forms; Z is the maximum load. Breakage occurs at W under a smaller load than at Z. A substance which has a fair elongation during the plastic stage is called ductile, while if the elongation is very small it is said to be brittle.

Given a table of tensile strengths of various metals, we can calculate the maximum force or stress that any given section will stand.

Table of tensile strengths

The tensile strength of a metal depends upon its condition, whether cast, annealed, work-hardened, heat-treated, etc.

	N/mm²	hbar	tonf/in²		N/mm²	hbar	tonf/in²
Lead	12–22	1.2–2.2	0.8–1.4	Brass	220–340	22–34	14–22
Zinc	30–45	3–4.5	2–3	Cast iron	220–300	22–30	14–20
Tin	30	3	2	Wrought iron	250–300	25–30	16–20
Aluminium	60–90	6–9	4–6	Mild steel	380–450	38–45	25–30
Copper	220–300	20–30	14–20	High tensile steel	600–800	60–80	

Example

A certain grade of steel has a tensile strength of 450 N/mm². What tensile force in newtons will be required to break a specimen of this steel cross-section 25 mm × 20 mm?

Area of cross-section = 500 mm²

$$\begin{aligned} \text{Force required} &= \text{tensile strength} \times \text{area of cross-section} \\ F &= 450 \times 500 \text{ newtons} \\ &= 225\,000 \text{ newtons} \\ &= 225 \times 10^3 \text{ newtons} = 0.225 \text{ MN}. \end{aligned}$$

The tensile strength of a metal depends largely upon the way it has been worked (hammered, rolled, drawn, etc.) during manufacture, its actual composition and the presence of impurities (see Fig. 1.16).

From the tensile test we can obtain:

(1) Yield point $= \dfrac{\text{yield stress}}{\text{original area of cross-section}}$ (N/mm² or hbar).

(2) Ultimate tensile stress (UTS)

$= \dfrac{\text{maximum stress}}{\text{original area of cross section}}$ (N/mm² or hbar).

(3) Percentage elongation on length between gauge marks

$$= \frac{\text{extension}}{\text{original length between gauge marks}} \times 100.$$

The distance between the gauge marks can be 50 mm or 5 × diameter of the specimen. Standard areas of cross-section can be 75mm² or 150 mm².

(4) Percentage reduction of area (R of A)

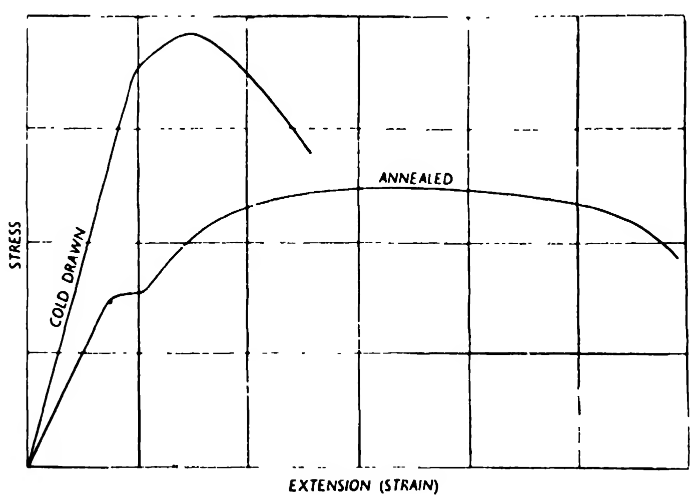
$$= \frac{\text{reduction of area at the fracture}}{\text{original area}} \times 100.$$

A typical example for one particular grade of weld metal is: Composition: 0.07% C, 0.4% Si, 0.68% Mn, remainder Fe. Yield stress 479 N/mm², ultimate tensile stress 556 N/mm², elongation on gauge length of 5 × *D*, 26%; reduction of area, 58%.

The elongation will depend on the gauge length. The shorter this is the greater the percentage elongation, since the greatest elongation occurs in the short length where 'waisting' or 'necking' has occurred. Reduction in area and elongation are an indication of the ductility of a metal.

As temperature rises there is usually a decrease in tensile strength and an increase in elongation, and the limit of proportionality is reduced so that at red heat application of stress produces plastic deformation. A fall in temperature usually produces the opposite effect. Internal stresses which

Fig 1.16. Stress strain diagram, for a steel in (1) annealed, (2) cold drawn condition.



have been left in a welded structure can be relieved by heating the members and lowering the limit of proportionality. The stresses then produce plastic deformation, and are relieved. This stress relief, however, may cause distortion.

Proof stress

Non-ferrous metals, such as aluminium and copper, etc., and also very hard steels, do not show a definite yield point, as just explained, and load–extension curves are shown in Fig. 1.17. A force which will produce a definite permanent extension of 0.1% or 0.2% of the gauge length is known as the proof stress (Fig. 1.18) and is measured in N/mm^2 or hbar.

Fig. 1.17

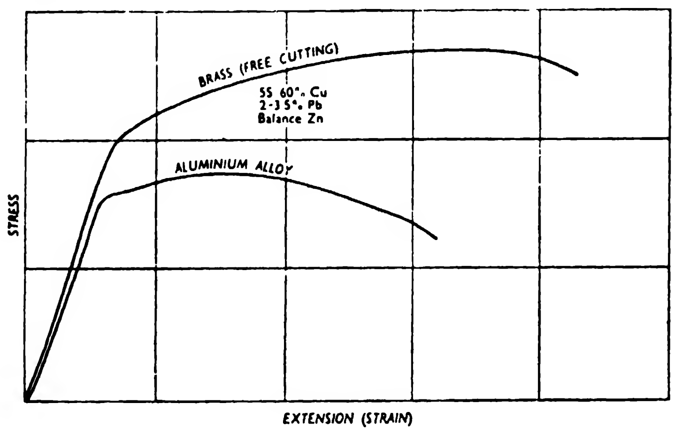
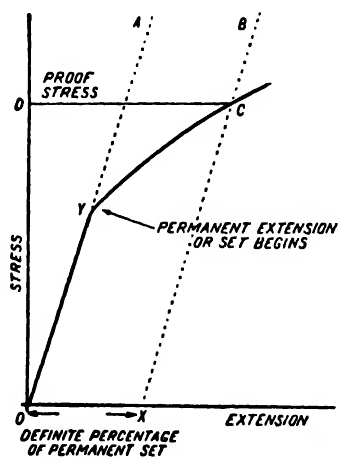


Fig. 1.18. Load–extension curve of hard steels and non-ferrous metals illustrating proof stress



Compressive stress

If the forces applied in the previous experiments on tensile strength are reversed, the body is placed under compression.

Compressive tests are usually performed on specimens having a short length compared with their diameter to prevent buckling when the load is applied. Ductile metals increase in diameter to a barrel shape and cracking round the periphery is some indication of the ductility of the specimen. For practical purposes E, the Young's modulus, can be assumed to be the same for compression and tension.

$$\text{Compressive stress} = \frac{\text{compressive load (N)}}{\text{area of cross section (mm}^2\text{)}}\ \text{N/mm}^2.$$

A good example of compressive stress is found in building and structural work. All foundations, concrete, brick and steel columns are under compressive stress, and in the making or fabrication of welded columns and supports, the strength of welded joints in compression is of great importance.

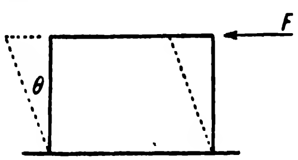
Shearing stress

If a cube has its face fixed to the table on which it stands and a force is applied parallel to the table on one of the upper edges, this force per unit area is termed a shearing stress and it will deform the cube, as indicated by the dotted line (Fig. 1.19). The angle θ through which the cube is deformed is a measure of the shearing strain, while the shearing stress will be in N/mm^2.

This is a very common type of stress in welded construction. For example, if two plates are lapped over each other and welded, then a load applied to the plates as shown puts the welds under a shearing stress. If the load is known and also the shearing strength of the metal of the weld, then sufficient metal can be deposited to withstand the load.

A welded structure should be designed to ensure that there is sufficient area of weld metal in the joint to withstand safely the load required.

Fig. 1.19



Mechanical properties of metals and the effect of heat on these properties

Plasticity may be defined as the ease with which a metal may be bent or moulded into a given shape. At ordinary temperatures, lead is one of the most plastic metals. The plasticity usually increases as temperature rises. Iron and steel are difficult to bend and shape when cold, but it becomes easy to do this when heated above red heat. Wrought iron, however, because of impurities in it, sometimes breaks when we attempt to bend it when hot (called hot shortness), and thus increase of temperatures is not always accompanied by an increase in plasticity.

Brittleness is the opposite of plasticity and denotes lack of elasticity. A brittle metal will break when a force is applied. Cast iron and high carbon steel are examples of brittle metals. The wrought iron in the above paragraph has become brittle through heating. Copper becomes brittle near its melting point, but most metals become less brittle when heat is applied. Carbon steel is an example; when cold it is extremely brittle, but can easily be bent and worked when hot. Brittle metals require care when welding them, due to the lack of elasticity.

Malleability is the property possessed by a metal of becoming permanently flattened or stretched by hammering or rolling. The more malleable a metal is, the thinner the sheets into which it can be hammered. Gold is the most malleable metal (the gold in a sovereign can be hammered into 4 m^2 of gold leaf, less than 0.0025 mm thick).

Copper is very malleable, except near its melting point, while zinc is only malleable between 140 and 160 °C. Metals such as iron and steel become much more malleable as the temperature rises and are readily hammered and forged.

The presence of any impurities greatly reduces the malleability, as we find that the metal cracks when it stretches.

Order of malleability when cold

(1) Gold	(3) Aluminium	(5) Tin	(7) Zinc
(2) Silver	(4) Copper	(6) Lead	(8) Iron.

Ductility is the property possessed by a substance of being drawn out into a wire and it is a property possessed in the greatest degree by certain metals. Like malleability this property enables a metal to be deformed mechanically. Metals are usually more ductile when cold, and thus wire drawing and tube drawing are often done cold, but not always.

In the wire-drawing operation, wire is drawn through a succession of tapered holes called *dies*, each operation reducing the diameter and increasing the deformation of the lattice structure. The brittleness thus increases and the wire must be softened again by a process termed annealing.

Order of ductility

(1) Gold	(3) Iron	(5) Aluminium	(7) Tin
(2) Silver	(4) Copper	(6) Zinc	(8) Lead.

Tenacity is another name for tensile strength. The addition of various substances to a metal may increase or decrease its tensile strength. Sulphur reduces the tenacity of steel while carbon increases it (see section on Tensile Strength).

Hardness is the property possessed by a metal resisting scratching or indentation. It is measured on various scales, the most common of which are: (1) Brinell, (2) Rockwell, (3) Vickers.

Table of comparative hardness

Material	Brinell	Vickers	Material	Brinell	Vickers
Lead	6	6	Brass 70/30,		
Tin	14	15	annealed	60	64
Aluminium			rolled	150	162
pure			Cast iron	150–250	160–265
annealed	19	20	Mild steel	100–120	108–130
Zinc	45	48	Stainless steel	150–165	160–180
Copper, cast	40–45	42–48			
cold worked	80–100	85–108			

Hardness decreases with rise in temperature. The addition of carbon to steel greatly increases its hardness after heat treatment, and the operations of rolling, drawing, pressing and hammering greatly affect it.

It will be noted that there is considerable latitude in the higher figures. Copper, for example, varies from 40 to 100 according to the way it is prepared. Copper is hardened by cold working, that is drawing, pressing and hammering, and this also decreases its ductility.

The tensile strength of steels can be approximately determined in N/mm^2 by multiplying their Brinell hardness figure by 3.25 for hard steels and by 3.56 for those in the soft or annealed condition.

Creep

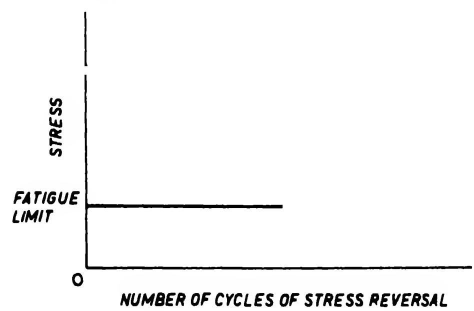
This is the term applied to the gradual change in dimensions which occurs when a load (tensile, compressive, bending, etc.) is applied to a specimen for a long period of time. Creep generally refers to the extension which occurs in a specimen to which a steady tensile load is applied over a period of weeks and months. In these tests it is generally found that the specimen shows greater extension for a given load over a long period than for a short period and may fracture at a load much less than its usual tensile load. The effect of creep is greater at elevated temperatures and is important, as for example, in pipes carrying high-pressure steam at high superheat temperatures. In creep testing, the specimen is surrounded by a heating coil fitted with a pyrometer. The specimen is heated to a given temperature, the load is applied and readings taken of the extension that occurs over a period of weeks, a graph of the results being made. The test is repeated for various loads and at various temperatures.

Special electrodes usually containing molybdenum are supplied for welding 'creep-resisting' steels, that is, steels which have a high resistance to elongation when stresses are applied for long periods of time at either ordinary or elevated temperatures.

Fatigue

Fatigue is the tendency which a metal has to fail under a rapidly alternating load, that is a load which acts first in one direction, decreases to zero and then rises to a maximum in the opposite direction, this cycle of reversals being repeated a very great number of times. If the stress is plotted against the number of stress reversals, the curve first falls steadily and then runs almost parallel to the stress reversal axis. The stress at which the curve becomes horizontal is the fatigue limit (fig. 1.20). The load causing failure is generally much less than would cause failure if it was applied as a steady load. Many factors, such as the frequency of the applied stress, tempera-

Fig 1.20 Number of cycles of stress reversal-stress curve



ture, internal stresses, variation in section and sharp corners leading to stress concentration, affect the fatigue limit. Methods of fatigue testing are given in Chapter 5.

Chemistry applied to welding

Elements, compounds and mixtures

All substances can be divided into two classes: (1) elements, (2) compounds.

An element is a simple substance which cannot be split up into anything simpler. For example, aluminium (Al), copper (Cu), iron (Fe), tin (Sn), zinc (Zn), sulphur (S), silicon (Si), hydrogen (H), oxygen (O) are all *elements.*

A table of the elements is given in Appendix 1, together with their chemical symbols.

A compound is formed by the chemical combination of two or more elements, and the property of the compound differs in all respects from the elements of which it is composed.

We have already mentioned the occurrence of matter in the form of molecules, and now it will be well to consider how these molecules are arranged among themselves and how they are made up.

If a mixture of iron filings and sand is made, we can see the grains of sand among the filings with the naked eye. This mixture can easily be separated by means of a magnet, which will attract the iron filings and leave the sand. Similarly, a mixture of sand and salt can be separated by using the fact that salt will dissolve in water, leaving the sand. In the case of mixtures, we can always separate the components by such simple means as this (called mechanical means).

Similarly, a mixture of iron filings and powdered sulphur can be separated, either by using a magnet or by dissolving the sulphur in a liquid such as carbon disulphide, in which it dissolves readily.

Now suppose we heat this mixture. We find that it first becomes black and then, even after removing the flame, it glows like a coal fire and much heat is given off. After cooling, we find that the magnet will no longer attract the black substance which is left, neither will the liquid carbon disulphide dissolve it. The black substance is, therefore, totally different in character from the iron filings or the sulphur. It can be shown by chemical means that the iron and sulphur are still there, contained in the black substance. This substance is termed a chemical compound and is called iron sulphide. It has properties quite different from those of iron and sulphur.

Previously it has been stated that molecules can be sub-divided.

Molecules are themselves composed of atoms, and the number of atoms contained in each molecule depends upon the substance.

For example, a molecule of the black iron sulphide has been formed by the combination of one atom of iron and one atom of sulphur joined together in a chemical bond. This may be written:

Fe + S = Fe—S

The molecules of some elements contain more than one atom. A molecule of hydrogen contains two atoms, so this is written:
$H_2 = O_{H} — {}_{H}O$. Similarly, a molecule of oxygen contains two atoms, thus: $O_2 = O_{O} — {}_{O}O$.

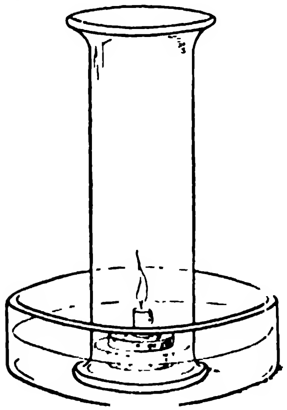
A molecule of copper contains only one atom, thus: $Cu = \overset{O}{Cu}$

The atmosphere

Let us now study the composition of the atmosphere, since it is of primary importance in welding.

Suppose we float a lighted candle, fastened on a cork, in a bowl of water and then invert a glass jar over the candle, as shown in Fig. 1.21. We find that the water will gradually rise in the jar, until eventually the candle goes out. By measurement, we find that the water has risen up the jar $\frac{1}{5}$ of the way, that is, $\frac{1}{5}$ of the air has been used up by the burning of the candle, while the remaining $\frac{4}{5}$ of the air still in the jar will not enable the candle to continue burning. The gas remaining in the jar is nitrogen (Fig. 1.22). It has no smell, no taste, will not burn and does not support burning. The gas which has been used up by the burning candle is oxygen.

Fig 1.21

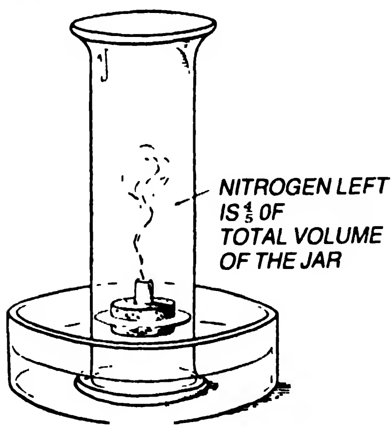


Evidently, then, air consists of four parts by volume of nitrogen to one part of oxygen. That oxygen is necessary for burning is very evident. Sand thrown on to a fire excludes the air, and thus the oxygen, and the fire is extinguished. If a person's clothes catch fire, rolling him in a blanket or mat will exclude the oxygen and put out the flames. In addition to oxygen and nitrogen the atmosphere contains a small percentage of carbon dioxide and also small percentages of the inert gases first discovered and isolated by Rayleigh and Ramsay. These gases are argon, neon, krypton and xenon. An inert gas is colourless, odourless, and tasteless, it is not combustible neither does it support combustion and it does not enter into chemical combination with other elements. Argon, which is present in greater proportion than the other inert gases, is used as the gaseous shield in 'inert gas welding' because it forms a protective shield around the arc and prevents the molten metal from combining with the oxygen and nitrogen of the atmosphere. Helium, which is the lightest of the inert gases, occurs only about 1 part in 200 000 in the atmosphere but occurs in association with other natural gases in large quantities especially in the United States, where it is often used instead of argon. The various gases of the atmosphere are extracted by fractionation of liquid air.

The percentage composition by volume, of dry air of the Earth's atmosphere is: nitrogen (N_2) 78.1, oxygen, (O_2) 20.9, argon (Ar) 0.93, carbon dioxide (CO_2) 0.03, neon (Ne) 0.0018, krypton (Kr) 0.000 14, xenon (Xe) 0.000 0086, helium (He) 0.000 52, hydrogen (H_2) 0.000 05, methane (CH_4) 0.000 15, oxides of nitrogen (nitrous oxide N_2O, etc.) traces of the order 0.000 05, ozone (O_3) variable traces of the order 0.000 04, ozone layer in polar regions of the order $\times 10^{-5}$ to $\times 10^{-6}$.

Note $10^{-1} = \frac{1}{10}$, $10^{-2} = \frac{1}{100}$, ..., $10^{-5} = \frac{1}{100\,000}$, $10^{-6} = \frac{1}{1\,000\,000}$, (p.p.m.)

Fig. 1.22



Nitrogen

Nitrogen is a colourless, odourless, tasteless gas, boiling point $-195.8\,°C$, which does not burn or support combustion. It is diatomic with an atomic weight of 14, and dissociates in the heat of the arc to form iron nitride, which reduces the ductility of a steel weld. For this reason it is not used as a shielding gas to any extent. It also forms nitrogen dioxide NO_2 and nitric oxide NO, which are toxic. It is widely dispersed in compound form in nitrates, ammonia and ammonium salts. It is produced by the liquefaction of air, and the considerable volumes produced by units such as those supplying tonnage oxygen to steel plants can be used as the top pressure gas in blast furnaces and for the displacement of air in tanks, pipelines, etc.

Nitrogen is supplied in compressed form in steel cylinders of 1.2, 3.1, 4.6, 6.2 and 7.77 m^3 capacity at pressures of 137 and 175 bar at 15 °C, and in liquid form by bulk tankers to an evaporator which in turn feeds gas into a pipeline. (See liquid oxygen.)

Argon

This monatomic gas, chemical symbol Ar and atomic weight 18, is present in the atmosphere to the extent of about 1% and is obtained by fractional distillation from liquid air. It has no taste, no smell, is non-toxic, colourless and neither burns nor supports combustion. It does not form chemical compounds and has special electrical properties. It is extensively used in welding, either on its own or mixed with carbon dioxide or hydrogen, in the welding of aluminium, magnesium, titanium, copper, stainless steel and nickel by the TIG and MIG processes and in plasma welding of stainless steel, nickel and titanium, etc. Argon is used for the inert gas filling of electric lamps and valves, with nitrogen, and in metal refining and heat treatment, for inert atmospheres. It is supplied in compressed form in steel cylinders of 1.72, 2.00, 8.48 and 9.66 m^3 capacity at pressures of 175 and 200 bar, and in liquid form delivered by road tankers which pump it directly into vacuum-insulated storage vessels as for liquid oxygen (q.v.).

Helium

Helium is an inert gas only present in the atmosphere to an extent of 0.000 052%. It is obtained from underground sources in the USA and is very much more expensive in this country than argon. It is monatomic with an atomic weight 4, is lighter than argon and is the lightest of the rare gases. Like the other inert gases it is colourless, odourless and tasteless, does not burn or support combustion, is non-toxic and does not form chemical compounds. Because of its lightness, a flow rate of 2 to $2\frac{1}{2}$ times

that of argon is required to provide an efficient gas shield in inert gas welding processes. Mixed with argon it gives a range of proprietary gases for TIG and MIG welding processes contained in steel cylinders of 8.5 to 9 m^3 capacity at a pressure of 200 bar at 15 °C.

Carbon dioxide CO_2

Carbon dioxide is now extensively used as a shielding gas in the gas shielded metal arc welding process. It is a non-flammable gas of molecular weight of 44.01, with a slightly pungent smell and is about $1\frac{1}{2}$ times as heavy as air (specific gravity relative to air is 1.53). It is soluble in water, giving carbonic acid H_2CO_3, and it can be readily liquefied, the liquid being colourless; the critical temperature (that is the temperature above which it is impossible to liquefy a gas by increasing the pressure) is 31.02 °C. Because its heat of formation is high it is a stable compound, enabling it to be used as a protective shield around the arc to protect the molten metal from contamination by the atmosphere, and it can be mixed with argon for the same purpose. During the CO_2 shielded metal arc process some of the molecules will be broken down or dissociated to form small quantities of carbon monoxide and oxygen. The carbon monoxide recombines with oxygen from the atmosphere to form CO_2 again and only very small quantities (the generally accepted threshold is 50 p.p.m.) escape into the atmosphere and the oxygen is removed by powerful deoxidizers in the welding wire. The gas is very much cheaper than argon; it is not an inert gas.

Carbon dioxide is formed when limestone is heated strongly in the lime kiln and also by the action of hydrochloric acid on limestone. It may be obtained as a by-product in the production of nitrogen and hydrogen in the synthesis of ammonia and also as a by-product in the fermentation process when yeast acts on sugar or starch to produce alcohol and carbon dioxide.

Large supplies for industrial use may be obtained by burning oil, coke or coal in a boiler. The steam generated can be used for driving prime movers for electricity generation and the flue gases, consisting of CO_2, nitrogen and other impurities, are passed into a washer where the impurities are removed and then into an absorber where the CO_2 is absorbed and the nitrogen thus separated. The absorber containing the CO_2 passes into a stripping column where the CO_2 is removed and water vapour set free, and is removed by a condenser. The CO_2 is then stored in a gas-holder from which it passes through a further purifying process, is then compressed in a compressor, passed through a drier and a condenser and stored in the liquid state at a pressure of 2 N/mm^2 at a temperature of − 18 °C, the storage tank being well insulated. The liquid CO_2 is then pumped into the cylinders used for welding purposes or into bulk supply tanks, or it may be further converted into the solid state (Cardice) which has a surface temperature of − 78.4 °C.

The use of CO_2 as a shielding gas in the MIG–MAG processes is fully discussed in the chapter on these processes and, in addition to this, the following are the main uses of the gas at the present time: in nuclear power stations, where it can be used for transference of heat from the reactor to the electricity generating unit; for the CO_2-silicate process in the foundry for core and mould making; for the soft drink trade where the gas is dissolved under pressure in the water of the mineral water or beer and gives a sparkle to the drink when the pressure is released; and in the solid state for refrigerated transport, the perishable foodstuffs being packed in heavily insulated containers with the solid CO_2, which evaporates to the gaseous state and leaves no residue.

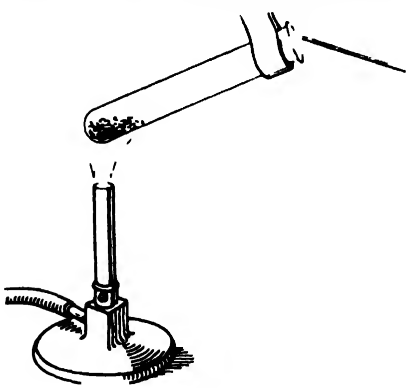
Oxygen

In view of the importance of oxygen to the welder, it will be useful to prepare some oxygen and investigate some of its properties.

Place a small quantity of potassium chlorate in a hard glass tube (test tube) and heat by means of a gas flame. The substance melts, accompanied by crackling noises. Now place a glowing splinter in the mouth of the tube. The splinter bursts into flame and burns violently (Fig. 1.23). Oxygen is being given off by the potassium chlorate and causes this violent burning. The glowing splinter test should *not* be used for testing for an escape of oxygen from welding plant.

Oxygen is prepared on a commercial scale by one of two methods: (1) liquefaction of air; (2) electrolysis of water. In the first method air is liquefied by reducing its temperature to about $-140\,°C$ and then compressing it to a pressure of 40 bar (4 N/mm^2). The pressure is then reduced and the nitrogen boils off first, leaving the liquid oxygen behind. This is then allowed to boil off into its gaseous form and is compressed to pressures of 137, 175 and 200 bar at 15 °C.

Fig. 1.23. Test for oxygen, glowing splinter bursts into flame.



The second method is generally used when there is a plentiful supply of cheap water power for generating electricity. An electric current is passed through large vats containing water, the current entering at the anode (positive) and leaving at the cathode (negative). The passage of the current splits up the water into hydrogen and oxygen. The hydrogen is collected from the cathode and the oxygen from the anode, there being twice the volume of hydrogen evolved as oxygen. (This operation is known as electrolysis.) The gases are then dried, compressed and stored in steel containers, the hydrogen being compressed to 172 bar (17.2 N/mm^2), similar to the oxygen.

Properties of oxygen. Oxygen is a colourless gas of atomic weight 16, boiling point $-183\,^{\circ}C$, with neither taste nor smell. It is slightly soluble in water, and this slight solubility enables fish to breathe the oxygen which has dissolved.

Oxygen itself does not burn, but it very readily supports combustion, as shown by the glowing splinter which is a test for oxygen.

If a piece of red-hot iron is placed in oxygen it burns brilliantly, giving off sparks. This is caused by the iron combining with the oxygen to form an *oxide*, in this case iron oxide (Fe_3O_4).

Oxidation. Most substances combine very readily with oxygen to form oxides, and this process is termed *oxidation.*

Magnesium burns brilliantly, forming a white solid powder, magnesium oxide, i.e.:

$$\begin{array}{ccccc} \text{magnesium} & + & \text{oxygen} & \rightarrow & \text{magnesium oxide} \\ 2Mg & + & O_2 & \rightarrow & 2MgO. \end{array}$$

When copper is heated to redness in contact with oxygen copper oxide is formed:

$$\begin{array}{ccccc} \text{copper} & + & \text{oxygen} & \rightarrow & \text{copper oxide} \\ 2Cu & + & O_2 & \rightarrow & 2CuO. \end{array}$$

Similarly, phosphorus burns with a brilliant flame and forms phosphorus oxide (P_2O_5). Sulphur burns with a blue flame and forms the gas, sulphur dioxide (SO_2).

Silicon, if heated, will combine with oxygen to form silica (SiO_2), which is sand:

$$\begin{array}{ccccc} \text{silicon} & + & \text{oxygen} & \rightarrow & \text{silica or oxide of silicon} \\ Si & + & O_2 & \rightarrow & SiO_2. \end{array}$$

Burnt dolomite, used as a refractory lining in the basic steel making process, is formed of magnesium and calcium oxides MgO.CaO.

When a chemical action takes place and heat is given out it is termed an exothermic reaction. The combination of iron and sulphur (p. 33), silicon and oxygen, and aluminium and iron oxide (p. 43) are examples. If heat is taken in during a reaction it is said to be endothermic. An example is the reaction which occurs when steam is passed over very hot coke. The oxygen combines with the carbon to form carbon monoxide and hydrogen is liberated, the mixture of the two gases being termed water gas, or:

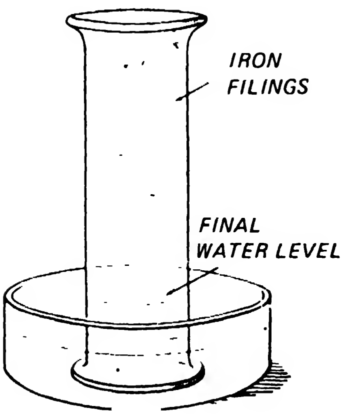
$$\begin{array}{ccccccc} \text{steam} & + & \text{carbon} & \rightarrow & \text{carbon monoxide} & + & \text{hydrogen} \\ H_2O & + & C & \rightarrow & CO & + & H_2. \end{array}$$

The rusting of iron. Moisten the inside of a glass jar so that small iron filings will adhere to the interior surface and invert the jar over a bowl of water, thus entrapping some air inside the jar (Fig. 1.24).

If the surface of the water inside the jar is observed, it is seen that as time passes and the iron filings become rusty, the surface of the water rises and eventually remains stationary at a point roughly $\frac{1}{5}$ of the way up the jar. From the similar experiment performed with the burning candle it can be seen that the oxygen has been used up as the iron rusts and nitrogen remains in the jar. The rusting of iron is, therefore, a process of surface oxidation.

This can further be demonstrated as follows: boil some water for some time in a glass tube (or test tube), in order to expel any dissolved oxygen, and then place a brightly polished nail in the water. Seal the open end of the tube by pouring melted vaseline down onto the surface of the water. The nail will now keep bright indefinitely, since it is completely out of contact with oxygen.

Fig. 1.24



Oxidation, from the welder's point of view, is the union of a metal with oxygen to form an oxide, i.e.:

metal + oxygen → metallic oxide.

Oxygen reacts with metals in various ways, depending on:

(1) *The character of the metal.* Magnesium burns very completely to form magnesium oxide, while copper, aluminium and chromium form a protective oxide film on their surface at room temperature.

(2) *Temperature.* Zinc at normal temperature only oxidizes slowly on the surface, but if heated to high temperature it burns with a bright bluish-white flame, forming a white powder, zinc oxide. Nearly all base metals can be converted to their oxide by heating them in oxygen.

(3) *The amount of surface exposed.* The larger the surface area the greater the amount of oxidation.

(4) *The amount of oxygen present.* Oxidation is much more rapid, for example, in a stream of pure oxygen than in air.

(5) *Presence of other substances.* Iron will not rust if no water is present.

Let us now examine the extent to which the more important metals in welding react to oxygen.

Iron and steel. If iron is excessively heated, oxygen is absorbed and oxidation or burning takes place, forming magnetic oxide of iron:

iron + oxygen → magnetic oxide of iron

$3Fe + 2O_2 \rightarrow Fe_3O_4$.

There are two other oxides of iron, ferric oxide (F_2O_3) or haematite, which is one of the sources of iron from the earth, and ferrous oxide (FeO), which is a black powder which takes fire when heated in air and forms ferric oxide.

Copper is extremely resistant to atmospheric corrosion, since it forms a film of oxide on its surface. This film is very unlike rust on iron, because it protects the metal and offers high resistance to any further attack. In time the oxide becomes changed to compounds having a familiar green colour such as sulphate of copper. When copper is brightly polished and exposed to a clean, dry atmosphere it tarnishes and becomes coated with a thin film of cuprous oxide (Cu_2O). If the temperature of the copper is now raised, the amount of oxidation increases proportionally and at high temperatures the copper begins to scale. The black scale formed is cupric oxide (CuO), while underneath this is another film of cuprous oxide (Cu_2O), which has a characteristic red colour.

Aluminium has a great affinity for oxygen and is similar to copper in that it forms a protective coating (of aluminium oxide, Al_2O_3) on its surface, which protects it against further attack. The depth of the film of oxide formed will depend upon the amount of corrosion, since the film adjusts itself to the amount of corrosive influences.

As the temperature increases little alteration takes place until near the melting point, when the rate of oxidation increases rapidly. It is the formation of this oxide which makes the welding of aluminium almost impossible unless a chemical (termed a flux) is used to dissolve it or an inert gas shield is used to prevent oxidation.

During the welding process, therefore, combination of the metal with oxygen may:

(1) Produce a gaseous oxide of a metal present in the weld and thus produce blow or gas holes.

(2) Produce oxides which, having a melting point higher than that of the surrounding metal, will form solid particles of *slag* in the weld metal.

(3) Produce oxides which will dissolve in the molten metal and make the metal brittle and weak. (The oxide in this case may form along the boundaries of the crystals of the metal.)

Some oxides are heavier than the parent metal and will tend to sink in the molten weld. Others are lighter and will float to the top. These are less troublesome, since they are easier to remove.

Oxides of wrought iron and steel, for example, melt very much below the temperature of the parent metal and, being light, float to the surface as a scale. Thus, if care is taken in the welding process, the oxide is not troublesome.

In the case of cast iron, however, the oxide melts at a temperature above that of the metal; consequently, it would form solid particles in the weld if not removed. For this reason a 'flux' is used which combines with the oxide and floats it to the surface. In welding copper, aluminium, nickel and brass, for example, a flux must be used to remove the oxides formed (see pp. 55–7).

The two most common causes of oxidation in welding are absorption of oxygen from the atmosphere, and use of an incorrect flame with excess oxygen in gas welding.

Reduction or deoxidation. Reduction takes place when oxygen is removed from a substance. Evidently it is always accompanied by oxidation, since the substance that removes the oxygen will become oxidized.

The great affinity of aluminium for oxygen is made use of in the thermit process of welding and provides an excellent example of chemical *reduction.*

Suppose we mix some finely divided aluminium and finely divided iron oxide in a crucible or fireclay dish. Upon setting fire to this mixture it burns and great heat is evolved with a temperature as high as 3000 °C. This is due to the fact that the aluminium has a greater affinity for oxygen than the iron has, when they are hot, and as a result the aluminium combines with the oxygen taken from the iron oxide. Thus the pure iron is set free in the molten condition. The action is illustrated as follows:

$$\text{iron oxide} + \text{aluminium} \rightarrow \text{aluminium oxide} + \text{iron}$$
$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe.$$

This is the chemical action which occurs in an incendiary bomb. The detonator ignites the ignition powder which sets fire to the thermit mixture. This is contained in a magnesium–aluminium alloy case (called Elektron) which also burns due to the intense heat set up by the thermit reaction.

Since oxygen has been taken from the iron, the iron has been *reduced* or deoxidized and the aluminium is called the reducing agent. To prevent oxidation taking place in a weld, silicon and manganese are used as deoxidizers. More powerful deoxidizers such as aluminium, titanium and zirconium (triple deoxidized) are added when oxidizing conditions are more severe, as for example in CO_2 welding and also in the flux cored continuous wire feed process without external gas shield, and the deoxidizers control the quality of the weld metal.

Note. Hydrogen is an electro-positive element, while oxygen is an electro-negative element. Therefore, oxidation is often spoken of as an increase in the ratio of the electro-negative portion of a substance, while reduction is an increase in the ratio of the electro-positive portion of a substance.

Examples of:

Oxidizing agents	*Reducing agents*
(1) Oxygen	(1) Hydrogen
(2) Ozone	(2) Carbon
(3) Nitric acid	(3) Carbon monoxide
(4) Chlorine	(4) Sulphur dioxide (at low temperatures)
(5) Potassium chlorate	(5) Sulphuretted hydrogen
(6) Potassium nitrate	(6) Zinc dust
(7) Manganese dioxide	(7) Aluminium.
(8) Hydrogen peroxide	
(9) Potassium permanganate	

Note. Dry SO_2 at welding temperatures behaves as an oxidizing agent and oxidizes carbon to carbon dioxide and many metallic sulphides to sulphates.

Acetylene

Acetylene is prepared by the action of water on calcium carbide (CaC_2). The carbide is made by mixing lime (calcium oxide) and carbon in an electric arc furnace. In the intense heat the calcium of the lime combines with the carbon, forming calcium carbide and, owing to the high temperatures at which the combination takes place, the carbide is very hard and brittle. It contains about 63% calcium and 37% carbon by weight and readily absorbs moisture from the air (i.e. it is hygroscopic); hence it is essential to keep it in airtight containers. The reaction is:

$$\begin{array}{ccccccc} \text{calcium oxide} & & & & & & \\ \text{or quicklime} & + & \text{carbon} & \rightarrow & \text{calcium carbide} & + & \text{carbon monoxide} \\ CaO & + & 3C & \rightarrow & CaC_2 & + & CO. \end{array}$$

The carbon monoxide burns in the furnace, forming carbon dioxide.

When water acts on calcium carbide, the gas acetylene is produced and slaked lime remains:

$$\begin{array}{ccccccc} \text{calcium carbide} & + & \text{water} & \rightarrow & \text{acetylene} & + & \text{slaked lime} \\ CaC_2 & + & 2H_2O & \rightarrow & C_2H_2 & + & Ca(OH)_2. \end{array}$$

Acetylene is a colourless gas, slightly lighter than air, only very slightly soluble in water, with a pungent smell largely due to impurities. It burns in air with a sooty flame but when burnt in oxygen the flame has a bright blue inner cone. It can be ignited by a spark or even by hot metal and forms explosive compounds with copper and silver so that copper pipes and fittings should never be used with it.

If compressed it is explosive but it is very soluble in acetone, which can dissolve 300 times its own volume at a pressure of 1.2 N/mm^2 or 12 bar and the acetone is carried on a porous medium in the cylinder which stands vertical when in store or use. Nominal contents vary from 0.57 to 8.69 m^3 at 15 °C.

Liquid petroleum gas (LPG). Propane C_3H_8, butane or C_4H_{10}. Propane is a flammable gas used as a fuel gas with either air or oxygen for heating and cutting operations. Its specific gravity compared with air is 1.4–1.6 (butane 1.9–2.1) so that any escaping gas collects at ground level and an artificial stenchant is added to the gas to warn personnel of its presence since it acts as an asphyxiant. Its boiling point at a pressure of 1 atmosphere is − 42 °C (butane − 7 °C) and the air-propane and oxy-propane flames have a greater calorific value than air-natural gas or oxy-natural gas for the same conditions of operating pressure. Flame temperature and hence cutting speeds are lower for oxy-propane than oxy-acetylene but propane is considerably cheaper than acetylene.

Note. The oxy-propane flame cannot be used for welding.

Propane burns in air to form carbon dioxide and water and is supplied in steel cylinders painted red in weights 4.8–47 kg, being sold by weight. It is also supplied by tanker to bulk storage tanks in a similar way to oxygen and nitrogen. Liquid natural gas (LNG) is similarly supplied.

Carbon

Carbon is of great importance in welding, since it is present in almost every welding operation. It is a non-metallic element, and is remarkable in that it forms about half a million compounds, the study of which is termed *organic chemistry*.

Carbon can exist in three forms. Two of these forms are crystalline, namely diamond and graphite, but the crystals of a diamond are of a different shape from those of graphite. (Carbon is found in grey cast iron as graphite.) Ordinary carbon is a third form, which is non-crystalline or *amorphous*. Carbon forms with iron the compound ferric carbide, Fe_3C, known as cementite. The addition of carbon to pure iron in the molten state is extremely important, since the character of the iron is greatly changed. Diamond and graphite are allotropes of carbon. Allotropy is the existence of an element in two or more forms.

Carbon is found in organic compounds such as acetylene (C_2H_2), hexane (C_6H_{14}), sugar ($C_{12}H_{22}O_{11}$), ethyl alcohol (C_2H_5OH), propane (C_3H_8), butane (C_4H_{10}), methane (CH_4), natural gas, etc.

Graphite used to be considered as a lead compound, but it is now known that it is a crystalline form of carbon. It is greasy to touch and is used as a lubricant and for making pencils.

The oxides of carbon. Carbon dioxide (CO_2) is heavier than air and is easily identified. It is formed when carbon is burnt in air, hence is present when any carbon is oxidized in the welding operation:

$$\text{carbon} + \text{oxygen} \rightarrow \text{carbon dioxide}$$
$$C + O_2 \rightarrow CO_2.$$

It will not burn, neither will it support combustion. It turns lime water milky, and this is the usual test for it. When it dissolves in the moisture in the air or rain it forms carbonic acid, which hastens corrosion on steel (see p. 54).

Carbon monoxide is formed when, for example, carbon dioxide is passed through a tube containing red-hot carbon:

$$\text{carbon} + \text{carbon dioxide} \rightarrow \text{carbon monoxide}$$
$$C + CO_2 \rightarrow 2CO.$$

Hence it may be formed from carbon dioxide during the welding process.

It is a colourless gas which burns with a blue, non-luminous flame. It is not soluble in water, has no smell and is very poisonous, producing a form of asphyxiation. Exhaust fumes from petrol engines contain a large proportion of carbon monoxide and it is the presence of this that makes them poisonous.

Carbon monoxide readily takes up oxygen to form carbon dioxide. It is thus a reducing agent and it can be made to reduce oxides of metals to the metals themselves.

The following poisonous gases may be formed during welding operations depending upon the process used, the material being welded, its coating and the electrode type:

Gas	*Example of formation*
Carbon monoxide	In CO_2 welding due to dissociation of some of the CO_2 in the heat of the arc.
Ozone, O_3	Due to oxygen in the atmosphere being converted to ozone by the ultraviolet radiation from the arc.
Phosgene, $COCl_2$	When trichloroethylene ($CHCl.CCl_2$), used for degreasing is heated or exposed to ultraviolet radiation from the arc.

Non-poisonous gases such as carbon dioxide and argon act as asphyxiants when the oxygen content of the atmosphere falls below about 18%. Fumes and pollutant gases also occur during welding due, for example, to the break-up of the electrode coating in metal arc welding and the vaporization of some of the metal used in the welding process. The concentrations of these are governed by a Threshold Limit Value (TLV) and the limits are expressed in parts per million (p.p.m.).

Combustion or burning

The study of combustion is very closely associated with the properties of oxygen. When burning takes place, a chemical action occurs. If a flame is formed, the reaction is so vigorous that the gases become luminous. Hydrogen burns in air with a blue, non-luminous flame to form water. In the oxy-hydrogen flame, hydrogen is burnt in a stream of oxygen. This causes intense heat to be developed, with a flame temperature of about 2800 °C.

The oxy-coal-gas flame is very similar, as the coal gas consists of hydrogen, together with other impurities (methane, carbon monoxide and

other hydrocarbons). Because of these impurities, the temperature of this flame is much lower than when pure hydrogen is used. The oxy-acetylene flame consists of the burning of acetylene in a stream of oxygen. Acetylene is composed of carbon and hydrogen (C_2H_2), and it is a gas which burns in air with a very smoky flame, the smoke being due, as in the case of a candle, to incomplete combustion of the carbon:

$$\begin{array}{ccccccc} \text{acetylene} & + & \text{oxygen} & \rightarrow & \text{carbon} & + & \text{water} \\ 2C_2H_2 & + & O_2 & \rightarrow & 4C & + & 2H_2O. \end{array}$$

By using, however, a special kind of burner, we have almost complete combustion and the acetylene burns with a very brilliant flame, due to the incandescent carbon.

The oxy-acetylene welding flame

When oxygen is mixed with the acetylene in approximately equal proportions a blue, non-luminous flame is produced, the most brilliant part being the blue cone at the centre. The temperature of this flame is given, with others, in the table:

Temperatures of various flames

Oxy-acetylene	3100 °C
Oxy-butane (Calor-gas)	2820 °C
Oxy-propane (liquefied petroleum gas, LPG)	2815 °C
Oxy-methane (natural gas)	2770 °C
Oxy-hydrogen	2825 °C
Air-acetylene	2325 °C
Air-methane	1850 °C
Air-propane	1900 °C
Air-butane	1800 °C

(Metal arc: 6000 °C upwards depending on type of arc).

This process of combustion occurs in two stages: (1) in the innermost blue, luminous cone; (2) in the outer envelope. In (1) the acetylene combines with the oxygen supplied, to form carbon monoxide and hydrogen:

$$\begin{array}{ccccccc} \text{acetylene} & + & \text{oxygen} & \rightarrow & \text{carbon monoxide} & + & \text{hydrogen} \\ C_2H_2 & + & O_2 & \rightarrow & 2CO & + & H_2. \end{array}$$

In (2) the carbon monoxide burns and forms carbon dioxide, while the hydrogen which is formed from the above action combines with oxygen to form water:

$$\begin{array}{ccccccccc} \text{carbon} & & & & & & \text{carbon} & & \\ \text{monoxide} & + & \text{hydrogen} & + & \text{oxygen} & \rightarrow & \text{dioxide} & + & \text{water} \\ CO & + & H_2 & + & O_2 & \rightarrow & CO_2 & + & H_2O. \end{array}$$

The combustion is therefore complete and carbon dioxide and water (turned to steam) are the chief products of the combustion. This is shown in Fig. 1.25. If insufficient oxygen is supplied, the combustion will be incomplete and carbon will be formed.

From this it will be seen that the oxy-acetylene flame is a strong *reducing* agent, since it absorbs oxygen from the air in the outer envelope. Much of its success as a welding flame is due to this, as the tendency to form oxides is greatly decreased. For complete combustion, there is a correct amount of oxygen for a given amount of acetylene. If too little oxygen is supplied, combustion is incomplete and carbon is set free. This is known as a carbonizing or carburizing flame. If too much oxygen is supplied, there is more than is required for complete combustion, and the flame is said to be an oxidizing flame.

For usual welding purposes the neutral flame, that is neither carbonizing nor oxidizing, is required, combustion being just complete with excess of neither carbon nor oxygen. For special work an oxidizing or carbonizing flame may be required, and this is always clearly indicated.

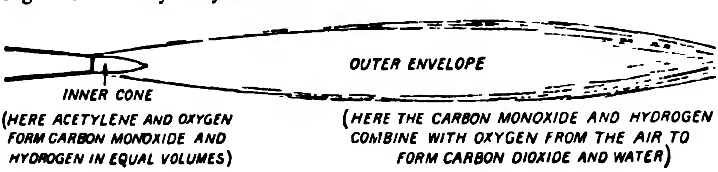
Silicon (Si)

Silicon is an element closely allied to carbon and is found in all parts of the earth in the form of its oxide, silica (SiO_2). In its free state, silica is found as quartz and sand. Silicon is also found combined with certain other oxides of metals in the form of silicates. Silicates of various forms are often used as the flux coverings for arc-welding electrodes and are termed 'siliceous matter'.

Silicon exists either as a brown powder or as yellow-brown crystals. It combines with oxygen, when heated, to form silica, and this takes place during the conversion of iron to steel. Silicon is present, mixed in small proportions with the iron, and, when oxygen is passed through the iron in the molten state, the silicon oxidizes and gives out great heat, an exothermic reaction.

Silicon is important in welding because it is found in cast iron (0.5–3.5%) and steel and wrought iron (up to 0.1%). It is found up to 0.3% in steel castings since it makes the steel flow easily in the casting process.

Fig. 1.25. The oxy-acetylene flame.



It is particularly important in the welding of cast iron, because silicon aids the formation of graphite and keeps the weld soft and machinable. If the silicon is burnt out during welding the weld becomes very hard and brittle. Because of this, filler rods for oxy-acetylene welding cast iron contain a high percentage of silicon, being known as 'silicon cast iron rods'. This puts back silicon into the weld to replace that which has been lost and thus ensures a sound weld.

By mixing silica (sand) and carbon together and heating them in an electric furnace, silicon carbide or carborundum is formed:

$$\begin{array}{ccccccc} \text{silica} & + & \text{carbon} & = & \text{silicon carbide} & + & \text{carbon monoxide} \\ SiO_2 & + & 3C & = & SiC & + & 2CO \end{array}$$

Carborundum is used for all forms of grinding operations. Silica bricks, owing to their heat-resisting properties, are used for lining furnaces.

Iron (Fe)

Iron has a specific gravity of 7.8, melts at 1530 °C and has a coefficient of expansion of 0.000 0 12 per degree C.

Pure iron is a fairly soft, malleable metal which can be attracted by a magnet.

All metallic mixtures and alloys containing iron are termed ferrous, while those such as copper, brass and aluminium are termed non-ferrous.

Iron combines directly with many non-metallic elements when heated with them, and of these the following are the most important to the welder:

With sulphur it forms iron sulphide (FeS).

With oxygen is forms magnetic oxide of iron (Fe_3O_4).

With nitrogen it forms iron nitride (Fe_4N).

With carbon it forms iron carbide (Fe_3C, called cementite).

Steel, for example, is a mixture of iron and iron carbide.

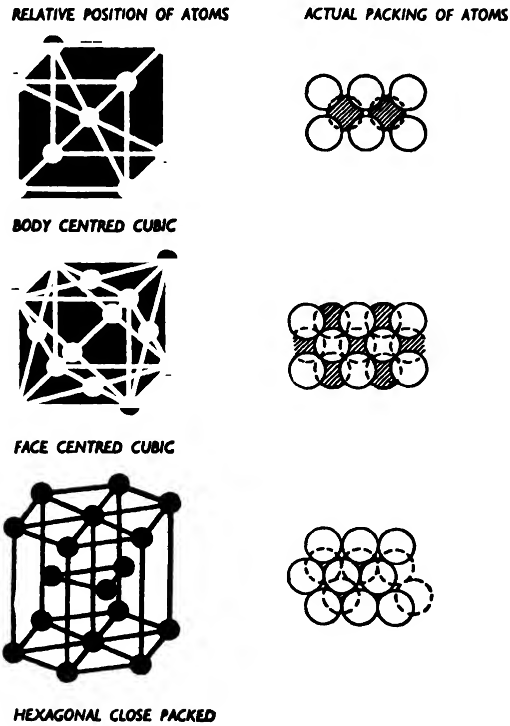
Formation of metallic crystals

We have seen that atoms in solid substances take up regular geometrical patterns termed as space lattice. There are many types of space lattice but atoms of pure metals arrange themselves mainly into three of the simpler forms termed: (1) body-centred cubic, (2) face-centred cubic, (3) hexagonal close packed. These are shown in Fig. 1.26. In body-centred cubic, atoms occupy the eight corners of a cube with one atom in the centre of the cube giving a relatively open arrangement. Face-centred cubic has eight atoms at the corners of a cube with six atoms, one in the centre of each face, giving a more closely packed arrangement. Hexagonal close packed is formed by six atoms at the corners of a regular hexagon with one in the

centre, placed over a similar arrangement and with three atoms in the hollows separating top and bottom layer. The student can very simply obtain the three-dimensional picture of these arrangements by using ping-pong balls to represent atoms. Copper and aluminium have a face-centred cubic lattice, magnesium a hexagonal close packed. Iron has a body-centred cubic lattice below 900°C (alpha iron, α), this changes to face-centred cubic from 900 °C to 1400 °C (gamma iron, γ), and reverts to body-centred cubic from 1400 °C to its melting point at about 1500 °C (delta iron, δ). These different crystalline forms are allotropic modifications.

When a liquid (or pure molten) metal begins to solidify or freeze, atoms begin to take up their positions in the appropriate lattice at various spots or nuclei in the molten metal, and then more and more atoms add themselves to the first simple lattice, always preserving the ordered arrangements of the lattice, and the crystals thus formed begin to grow like the branches of a tree and, from these arms, other arms grow at right angles, as shown in Fig. 1.27. Eventually these arms meet arms of neighbouring crystals and no further growth outwards can take place. The crystal then increases in size,

Fig. 1.26. Types of crystals.



within its boundary, forming a solid crystal, and the junction where it meets the surrounding crystals becomes the crystal or grain boundary. Its shape will now be quite unlike what it would have been if it could have grown without restriction; hence it will have no definite shape.

If we examine a pure metal structure under a microscope we can clearly see these boundary lines separating definite areas (Fig. 1.28), and most pure metals have this kind of appearance, it being very difficult to tell the

Fig. 1.27

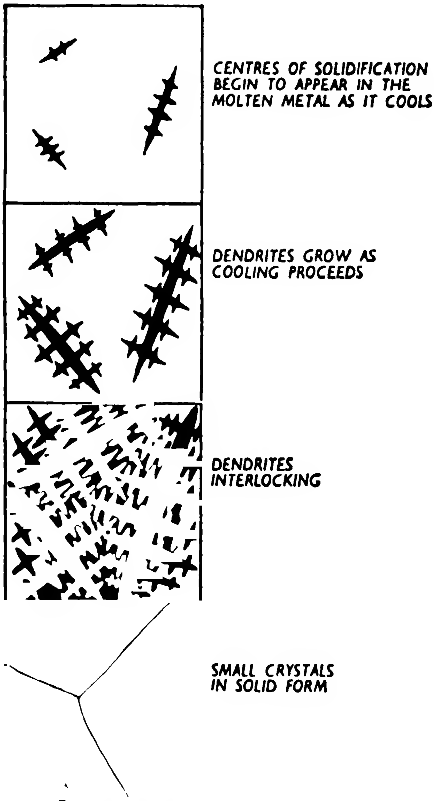
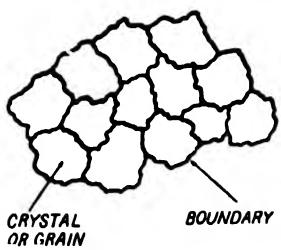


Fig. 1.28



difference between various pure metals by viewing them in this way. If impurities are present, they tend to remain in the metal which is last to solidify and thus appear between the arms of the dendrites along the grain boundaries.

This method of crystallization is termed *dendritic crystallization* and the above crystal is termed a dendrite (Fig. 1.29). It can be observed when frost forms on the window pane, and this gives a good illustration of the method of crystal formation, since the way in which the arms of the dendrite interlock can clearly be seen. (The frost, however, only forms on a flat surface, while the metal crystal forms in three dimensions.) Crystals which are roughly symmetrical in shape are termed equi-axed.

Recrystallization commences at a definite temperature, and if the temperature is increased greatly above this, the grains become much larger in size, some grains absorbing others. Also, the longer that the metal is kept in the heated condition the larger the grains grow. The rate at which cooling occurs in the case of metals also determines the size of the grains, and the slower the cooling the larger the grains (see grain growth, Fig. 2.17). Large, coarse crystals or grains have a bad effect on the mechanical properties of the metal and decrease the strength. If heat conditions are suitable crystals may grow in one direction, then being long and narrow. These are termed columnar crystals. Fig. 2.22 shows a mild steel arc weld run on a steel plate. There is a thin layer of chill cast crystals on the upper surface of the weld since they cooled quickly in contact with the atmosphere and have had no time to grow. They have been left out for the sake of clarity. Below these are columnar crystals growing towards the centre of greatest heat. Lower still are equi-axed crystals showing grain growth, while below these is a region of small crystals where recrystallization has occurred.

Cold work distorts the crystals in the direction of the work (see Fig. 2.22).

The size of the grains, therefore, depends on:

(1) The type of metal.
(2) The temperature to which the metal has been raised.
(3) The length of time for which the metal is kept at high temperature.
(4) The rate of cooling.

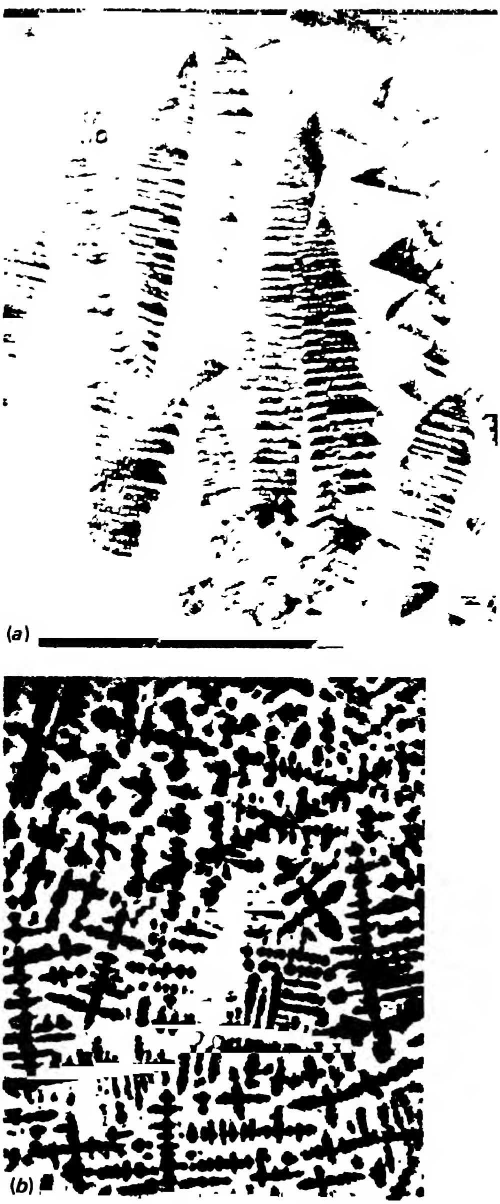
Crystals of alloys

If one or more metals is added to another in the molten state, they mix together forming a solution, termed an *alloy*.

When this alloy solidifies:

(1) It may remain as a solution, in which case we get a crystal structure similar to that of pure metal.

Fig. 1.29
(*a*) Fir tree (dendritic) crystals in the shrinkage cavity of a large carbon steel casting The crystals have grown mainly in one direction, but the growth of the lateral arms at right angles to the main axes is clearly seen ($\frac{1}{2}$ actual size.)
(*b*) Portion of a nickel chrome molybdenum steel ingot showing interlocking of the dendrites. In this case crystallization has started from a series of centres, and the growth of any one dendritic crystal has been restricted by the presence of neighbouring crystals



(*a*) (*b*)

(2) The two metals may tend to separate out before solidifying, in which case the crystal structure will be a mixture of the crystals of the two metals, intimately mixed together.

Copper–nickel and chromium–iron are examples of the first kind of crystal formation, while lead–tin and copper–zinc are examples of the second kind.

Welding has a very great effect on the structure and crystal form of metals, and the above brief study will enable the reader to have a clearer understanding of the problem.

Metallic alloys and equilibrium diagrams are dealt with in much greater detail in Chapter 3.

Effects of corrosion on welds in steel

Corrosion is a chemical action on a metal, resulting in the conversion of the metal into a chemical compound.

The rusting of iron, which we have considered, is a good example. In the presence of air and water, the iron eventually changes into oxides and hydroxides of iron and then into hydrated carbonates.

In addition to this type of attack, the matter which is suspended in the atmosphere also assists corrosion. The very small proportion of carbon dioxide in the atmosphere becomes dissolved in the rain, forming very weak carbonic acid, and this attacks steel, again forming carbonates. In and near large towns the atmosphere contains a very much larger proportion of suspended matter than in the country. Smoke and fumes contain, among other compounds, sulphur dioxide, which again dissolves in rain to form sulphurous acid. This is oxidized into dilute sulphuric acid, which again attacks the steel, the attack being much stronger than in the case of the carbonic acid.

Near the coast, the salt in the atmosphere forms hydrochloric acid and caustic soda, and severe corrosion occurs in these areas.

In addition to this direct form of chemical attack there is a second type of attack which is at first not so apparent. When two different metals are placed in a conducting liquid, such as a dilute acid or alkali, an electric cell or battery is formed, one of the metals becoming electro-positive, while the other becomes electro-negative. The difference of electrical pressure or voltage between these two plates will depend upon the metals chosen.

In the case of a welded joint, if the weld metal is of different structure from the parent metal, we have, if a conducting liquid is present, an electric cell, the plates of which are connected together or short-circuited. The currents which flow as a result of this are extremely minute, but nevertheless they greatly accelerate corrosion. This effect is called electrolysis, and its harmful effects are now well known.

The deposited metal in the weld is never of the same composition as the parent metal, although it may have the same properties physically. In the welded region, therefore, dissimilar metals exist, and in the presence of dilute carbonic acid from the atmosphere (or dilute sulphuric acid as the case may be) electrolytic action is set up and the surfaces of the steel become pitted. Now if the weld metal is electro-positive to the parent metal, the weld metal is attacked, since it is the electro-positive plate which suffers most from the corrosive effect. On the other hand, if the parent steel plate is electro-positive to the weld metal, the plate is attacked and since its surface area is much larger than that of the weld, the effect of corrosion will be less than if the weld had been attacked.

Thus, weld metal should be of the same composition throughout its mass to prevent corrosion taking place in the weld itself. It should also be electro-negative to the parent metal to prevent electrolytic action causing pitting of its surface, and it must resist surface oxidation at least as well as the parent metal.

Fluxes

Oxy-acetylene welding

Most metals in their molten condition become oxidized by the absorption of oxygen from the atmosphere. For example, aluminium always has a layer of aluminium oxide over its surface at normal temperature, and has a very great affinity for oxygen. To make certain that the amount of oxidation is kept a minimum, that any oxides formed are dissolved or floated off, and that welding is made as easy and free from difficulties as possible, fluxes are used. Fluxes, therefore, are chemical compounds used to prevent oxidation and other unwanted chemical reactions. They help to make the welding process easier and ensure the making of a good, sound weld.

The ordinary process of soldering provides a good example. It is well known that it is almost impossible to get the solder to run on to the surface to be soldered unless it is first cleaned. Even then the solder will not adhere uniformly to the surface. If now the surface is lightly coated with zinc chloride or killed spirit (made by adding zinc to hydrochloric acid or spirits of salt until the effervescing action ceases), the solder runs very easily wherever the chloride has been. This 'flux' has removed all the oxides and grease from the surface of the metal by chemical action and presents a clean metal surface to be soldered. This makes the operation much easier and enables a much better bond with the parent metal to be obtained. Fluxes used in oxy-acetylene welding act in the same way. Flux-covered rods are now available for bronze and aluminium welding.

Brass and bronze

A good flux must be used in brass or bronze welding, and it is usual to use one of the borax type, consisting of sodium borate with other additions. (Pure borax may be used.) The flux must remove all oxide from the metal surfaces to be welded and must form a protective coating over the surfaces of the metal, when they have been heated, so as to prevent their oxidation. It must, in addition, float the oxide, and the impurities with which it has combined, to the top of the molten metal.

Aluminium and aluminium alloys

The flux must chemically remove the film of aluminium oxide (melting point over 2000 °C) and must float any impurities to the surface of the molten pool. A typical flux contains, by weight, lithium chloride 0–30%, potassium fluoride 5–15%, potassium chloride 0.6% and the remainder sodium chloride. The fluxes are very hygroscopic (absorb moisture readily) and should always be kept in an airtight container when not in use. They are very corrosive and after welding the work should be well scrubbed in hot water or treated with a 5% solution of nitric acid in water to remove all traces of flux.

The use of these fluxes has now been largely superseded by the use of the TIG and MIG processes for the welding of aluminium, using inert gases and the arc for dispersal of the oxide films.

Cast iron

When welding wrought iron and mild steel the oxide which is formed has a lower melting point than the parent metal and, being light, floats to the surface as a scale which is easily removed after welding. No flux is, therefore, required when welding mild steel or wrought iron.

In the case of cast iron, oxidation is rapid at red heat and the melting point of the oxide is *higher* than that of the parent metal, and it is, therefore, necessary to use a flux which will combine with the oxide and also protect the metal from oxidation during welding. The flux combines with the oxide and forms a slag which floats to the surface and prevents further oxidation. Suitable fluxes contain sodium, potassium or other alkaline borates, carbonates, bicarbonates and slag-forming compounds.

Copper

Copper may be welded without a flux, but many welders prefer to use one to remove surface oxide and prevent oxidation during welding. Borax is a suitable flux, and its only drawback is that the hard, glass-like scale of copper borate, which is formed on the surface after welding, is hard

to remove. Special fluxes, while consisting largely of borax, contain other substances which help to prevent the formation of this hard slag.

To sum up, we may state, therefore, that fluxes are used:

(1) To reduce oxidation.
(2) To remove any oxide formed.
(3) To remove any other impurities.

Because of this, the use of a flux:

(1) Gives a stronger, more ductile weld.
(2) Makes the welding operation easier.

It is important that *too much* flux should never be used, since this has a harmful effect on the weld.

Manual metal arc flux-covered electrodes

If bare wire is used as the electrode in MMA welding many defects are apparent. The arc is difficult to strike and maintain using d.c.; with a.c. it is extremely difficult. The resulting 'weld' lacks good fusion, is porous, contains oxides and nitrides due to absorption of oxygen and nitrogen from the air, and as a result the weld is brittle and has little strength. To remedy these defects electrodes are covered with chemicals or fluxes which:

(1) Enable the arc to be struck and maintained easily on d.c. or a.c. supplies.
(2) Provide a shield of gases such as hydrogen or carbon dioxide to shield the molten metal in its transference across the arc and in the molten pool in the parent plate from reacting with the oxygen and nitrogen of the atmosphere to form oxides and nitrides, which are harmful to the mechanical properties of the weld.
(3) Provide a slag which helps to protect the metal in transit across the arc gap when the gas shield is not voluminous, and which when solidified protects the hot metal against oxidation and slows the rate of cooling of the weld; also slag metal reactions can occur which alter the weld metal analysis.

Also alloying elements can be added to the coverings in which case the core wire analysis will not match the weld metal analysis.

We have seen that an oxide is a compound of two elements, one of which is oxygen. Many oxides are used in arc welding fluxes, examples of which are: silicon dioxide SiO_2 (A), manganous oxide MnO (B), magnesium oxide MgO (B), calcium oxide CaO (B), aluminium oxide Al_2O_3 (Am), barium oxide BaO (B), zinc oxide ZnO (Am), ferrous oxide FeO (B). Oxides may be classified thus: acidic, basic and amphoteric, indicated by A, B and Am above (other types are dioxides, peroxides, compound oxides and neutral oxides). An acidic oxide reacts with water to form an acid thus:

SO_2 (sulphur dioxide) + H_2O = sulphurous acid (H_2SO_3).

In the case of silicon dioxide SiO_2, which is insoluble in water, it reacts similarly with fused sodium hydroxide (NaOH) to form sodium silicate and water thus:

$$SiO_2 + 2\ NaOH = Na_2SiO_3 + H_2O.$$

Basic oxides interact with an acid to form a salt and water only thus: calcium oxide (CaO) reacts with hydrochloric acid (HCl) to form calcium chloride ($CaCl_2$) and water:

$$CaO + 2\ HCl = CaCl_2 + H_2O.$$

Amphoteric oxides can exhibit either basic or acidic properties. Aluminium oxide (Al_2O_3) reacts with dilute hydrochloric acid as a basic oxide thus:

$$Al_2O_3 + 6\ HCl = 2AlCl_3 + 3H_2O,$$

but as an acidic oxide it reacts with sodium hydroxide thus:

$$Al_2O_3 + 2\ NaOH = 2\ NaAlO_2 + H_2O.$$

When oxides are mixed to form fluxes the ratio of the basic to acidic oxides is termed the basicity and is important, as for example in the fluxes used for submerged arc welding (q.v.) where the flux must be carefully chosen in conjunction with the electrode wire to give the desired mechanical properties to the weld metal.

To illustrate the action of the flux-covered electrode we may consider the reaction between a basic oxide such as calcium oxide (CaO) and an acidic oxide such as silicon dioxide (SiO_2). With great application of heat these will combine chemically to form calcium silicate, which is a slag, thus:

$$\begin{array}{ccccc} \text{calcium oxide} & + & \text{silicon dioxide} & \rightarrow & \text{calcium silicate} \\ CaO & + & SiO_2 & \rightarrow & CaSiO_3. \end{array}$$

Similarly if we use iron oxide (Fe_2O_3) and silicon dioxide (SiO_2) in the covering of the electrode, in the heat of the arc they will combine chemically to form iron silicate, which floats to the top of the molten pool as a slag, protects the hot metal from further atmospheric oxidation and slows down the cooling rate of the weld.

$$\begin{array}{ccccc} \text{iron oxide} & + & \text{silicon dioxide} & = & \text{iron silicate} \\ Fe_2O_3 & + & 3SiO_2 & = & Fe_2(SiO_3)_3 \end{array}$$

The most common slag-forming compounds are rutile (TiO_2), limestone ($CaCO_3$), ilmenite ($FeTiO_3$), iron oxide (Fe_2O_3), silica (SiO_2), manganese oxide (MnO_2) and various aluminium silicates such as felspar and kaolin, mica and magnesium silicates.

Deoxidizers such as ferrosilicon, ferromanganese and aluminium are also added to reduce the oxides that would be formed in the weld to a negligible amount.

The chemical composition of the covering also has an effect on the electrical characteristics of the arc. Ionizers such as salts of potassium are added to make striking and maintaining the arc easier, and for arcs of the same length there is a higher voltage drop when a coating releases hydrogen as the shielding gas than when one releases carbon dioxide. For a given current this higher voltage drop gives greater energy output from the arc, and hydrogen releasing coatings are usually cellulosic, giving a penetrating arc, thin slag cover and quite an amount of spatter. Other coatings are discussed in detail in the section in Chapter 8, under the heading 'Electrode classification (British)'.

For the arc welding of bronze (also copper and brass) the flux must dissolve the layer of oxide on the surface and, in addition, must prevent the oxidation of the metal by providing the usual sheath. These coatings contain fluorides (cryolite and fluorspar) and borates and the rods are usually operated on the positive pole of a direct current supply.

The flux of the aluminium rod is a mixture of chlorides and fluorides, as for oxy-acetylene welding of aluminium. It acts chemically on the oxide, freeing it, and this enables it to be floated to the surface of the weld. It is corrosive and also tends to absorb moisture from the air; hence the weld should be well cleaned with hot water on completion, while the electrodes should be stored in a dry place. In fact, all electrodes should be kept very dry, since the coatings tend to absorb moisture and the efficiency of the rod is greatly impaired if the covering is damp.

The manual metal arc welding of aluminium and its alloys has been largely superseded by the inert gas shielded-metal arc processes, TIG and MIG.

Materials used for electrode coatings

(1) Rutile. Rutile is a mineral obtained from rutile-bearing sands by suction dredging. It contains about 88–94% of TiO_2 and is probably the most widely used material for electrode coatings. Ilmenite is a naturally occurring mineral composed of the oxides of iron and titanium $FeTiO_3$ (FeO, TiO_2) with about 45–55% TiO_2. After separation of impurities it is ground to the required mesh size and varies from grey to brown in colour.

(2) Calcium carbonate or limestone is the coating for the basic coverings of electrodes. The limestone is purified and ground to required mesh size. The slag is very fluid and fluorspar is added to control fluidity. The deposited metal is very low in hydrogen content.

(3) Fluorspar or fluorite is calcium fluoride and is mined, separated from impurities, crushed, screened, and ground, and the ore constituents are

separated by a flotation process. Too great an addition of this compound to control slag fluidity affects the stability of the a.c. arc.

(4) Solka floc is cellulose acetate and is prepared from wood pulp. It is the main constituent of class 1 cellulose electrodes. Hydrogen is given off when it decomposes under the heat of the arc so that there is a large voltage drop and high power giving deep penetration. Arc control is good but there is hydrogen absorption into the weld metal.

(5) Felspar is an anhydrous silicate of aluminium associated with potash, soda, or calcium, the potash felspar being used for electrode coatings. It is used as a flux and a slag-producing substance. The potash content stabilizes the a.c. arc and it is generally used in association with the rutile and iron oxide–silica coatings. The crystalline ore is quarried and graded according to impurities, ground, and the powder finally air-separated. The binders in general use for the materials composing electrode coatings are silicates of potassium and sodium.

(6) Ball clay. A paste for an electrode coating must flow easily when being extruded and must hold liquid present so that it will not separate out under pressure; also the freshly extruded electrode must be able to resist damage when in the wet or green condition. Because of the way in which its molecules are arranged ball clay gives these properties to a paste and is widely used in those classes of electrodes in which the presence of hydrogen is not excluded. Found in Devon and Cornwall, it is mined, weathered, shredded, pulverized and finally sieved.

(7) Iron powder is added to an electrode coating to increase the rate of metal deposition. In general, to produce the same amount of slag with this powder added to a coating it generally has to be made somewhat thicker. To produce the iron powder, pure magnetic oxide of iron is reduced to cakes of iron in a bed of carbon, coke and limestone. The 'sponge cakes' which are formed are unlike ordinary iron in that they can be pulverized to a fine powder which is then annealed. Electrodes may contain up to 50% of iron powder.

(8) Ferromanganese is employed as a deoxidizer as in steel-making to remove any oxide that has formed in spite of the arc shield. It reacts with iron oxide to form iron and manganese dioxide, which mixes with the slag.

(9) Mica is a mineral found widely dispersed over the world. It is mined and split into sheets. The larger sizes are used for electrical purposes such as commutator insulation and the smaller pieces are ground into powder form. It is used in electrode coatings as a flux and it also assists the extrusion and gives improved touch welding properties with increase in slag volume.

(10) Sodium alginate is extracted from certain types of seaweed. It is used

in electrode coatings because when made into a viscous paste, it assists extrusion and is especially useful when the coating contains a large proportion of granules.

The flux coating on electrodes may be applied in one of the following ways:

(1) Solid extrusion.
(2) Extrusion with reinforcement.
(3) Dipping.

(1) Solid extrusion. This is the way in which most of the present-day electrodes are produced. The flux, in the form of a paste, is forced under pressure around the wire core. The thickness of the flux covering can be accurately controlled and is of even thickness all round the wire core, the method being suitable for high speed production. This covering, however, will not stand up to very rough handling, nor to bending (as is sometimes required when welding awkwardly placed joints) since the covering flakes off.

(2) Extrusion with reinforcement. In this method the reinforcement enables the covering to withstand more severe handling and bending without flaking. The reinforcement may be:

(*a*) An open spiral of yarn wound on the rod, the space between the spiral coils being filled with extruded flux.
(*b*) A close spiral of yarn wound over a solid extrusion of flux applied first to the wire coil, and this flux covering strengthened by a yarn or by a single or double helical wire winding.

(3) Dipping. The dipping process has been largely superseded by the other two methods. Certain rods having special applications are, however, still made by this process. Repeated dippings are used to give thicker coatings.

Method 1 is used almost entirely at the present time. Methods 2 and 3 are for reference only.

Fluxes used in submerged arc welding (often known as sub-arc)

In this method of automatic welding, the arc is struck between the wire electrode, which is fed continuously to the nozzle, and the work to be welded. Arc, molten pool and cooling metal are submerged beneath a layer of granulated flux evenly laid along the line of the weld from a hopper and laying pipe attached to the welding head. The flux is deposited in front of the arc as it travels and is of sufficient depth to submerge it. The

welding head may be tractor-driven over the work or the work may move below the fixed welding head as for circumferential seams. Thus:

(1) A layer of flux is formed under the heat of the arc, protecting arc, molten pool and cooling weld metal.
(2) There is neither spatter nor effect of UV or IR radiation.
(3) Deoxidation and alloying elements are easily added to the flux and hence the weld metal.
(4) The arc stability is increased and its characteristics varied.
(5) The weld contour and surface are shaped to give a good finish.

Fluxes for sub-arc welding usually consist of metallic oxides such as CaO, MgO and FeO and fluorides such as CaF_2 and may be divided into two classes: (1) fused, (2) agglomerated, according to the method of manufacture.

Fused fluxes. The constituents such as quartz, limestone and manganese dioxide (MnO_2) with small quantities of fluorspar and aluminium oxide (Al_2O_3) are melted in an electric arc furnace where the MnO_2 is reduced to MnO. When the melt attains the state of a glossy paste it can be cooled, crushed and then ground, and a suitable grain size obtained by sieving, the grains being about 0.2 1.6 mm diameter. This type of flux is homogeneous and was the first type of flux to be used.

Agglomerated fluxes. These are more easily manufactured than the fused type, being made at a lower temperature. They are heterogeneous because they include compounds in powder form whose grains join together by the agglomeration process and make larger grains, each grain having the correct proportion of each component. The dry powder is fed onto a rotating disc with the addition of water glass (a concentrated and viscous solution of sodium and potassium silicate) as a binding agent. The grains are then furnace-dried at about 700 800 °C and then sieved to give grains somewhat the same as for fused flux, 0.2–1.6 mm. Because of the lower manufacturing temperature this flux is more chemically active so that reactions take place between molten weld metal and molten flux during melting and solidification and fluxing ingredients are easily added to give the flux definite properties as follows:

(1) Deoxidation elements added (e.g. FeSi, FeMn, or FeSiMn) so that the process is not dependent upon the reduction of MnO_2 to MnO.
(2) Alloying elements added to give the flux varying properties.

(3) Easy slag removal and good weld appearance.
(4) High resistance to porosity.
(5) Low specific flux consumption (kg melted flux/kg melted electrode).

Basicity of fluxes used in submerged arc welding

We have already seen that there are three types of oxide, acidic, basic, amphoteric (p. 57). The chemical nature of a welding flux can be expressed as the basicity from the generally used formula, expressed in weights %:

$$B \text{ (basicity)} = \frac{CaO + MgO + Na_2O + K_2O + CaF_2 + \frac{1}{2}(MnO + FeO)}{SiO_2 + \frac{1}{2}(Al_2O_3 + TiO_2 + ZnO_2)}$$

The formula indicates the relation between basic and acidic oxides in the flux. It can be seen that MnO and FeO (amphoteric) are regarded as half basic, while TiO_2, ZnO_2 and Al_2O_3 are regarded as half acidic. The CaF_2 reacts with the SiO_2 to give CaO and is regarded as basic, reducing the activity of the SiO_2 thus:

$$SiO_2 + 2CaF_2 \rightarrow 2CaO + SiF_4,$$

the latter being given off as a gas.

Welding fluxes can thus be divided as follows:

Welding flux	Basicity	Melting point (°C
acidic	$\leqslant 0.9$	1100–1300
neutral	$= 0.9$–1.2	1300–1500
basic	$= 1.2$–2.0	> 1500
high basic	> 2.0	> 1500

Some microslag remains in the final weld metal, the quantity depending upon the melting temperature. Slags that solidify at temperatures above that of the weld pool have a weld deposit with a relatively small quantity of microslag compared with those that solidify at temperatures below that of the weld pool. If basic or high basic fluxes are used the microslag solidifies before the weld deposit and floats to the surface to join the top slag. With acid or neutral fluxes the slag has a lower melting point than the weld deposit and the microslag does not float up to the top slag so that more microslag is entrapped by the solidifying grains of the weld metal. A small quantity of microslag is advantageous to the strength of the weld and a method of determining the oxide slags present in the weld metal is

to measure the oxygen content, the acidic fluxes having greater than 770 ppm (parts per million), the basic fluxes 300–500 ppm and high basic fluxes less than 300 ppm. Use of an acidic flux may give an impact strength of 50 J at 0 °C, while use of neutral, basic or high basic fluxes under the same operating conditions may give values of 50 J at −20 °C, −40 °C and −60 °C respectively (ISO specimens).

The trouble is that as the basicity decreases the welding characteristics are improved, the arc is rendered more stable, weld appearance is improved and slag removal is made easier. In general, the flux should match the welding wire and parent metal, as shown by the makers. Choose the highest basicity compatible with impact, yield and tensile strength, and good arc characteristics with good weld profile and easy slag removal, and remember that in any weld the ratio of parent metal to weld metal depends upon the method of preparation of the joint

2

Metallurgy

Production and properties of iron and steel

Before proceeding to a study of iron and steel it will be well to understand how they are produced.

Iron is found in the natural form as iron ores. These ores are of four main types:

(1) Haematite, red or brown Fe_2O_3, containing 40–60% iron.

(2) Magnetite or magnetic oxide of iron, Fe_3O_4, containing up to 70% iron.

(3) Limonite, a hydrated ore, $Fe_2O_3 \cdot 3H_2O$, containing 20–50% iron.

(4) Siderite, a carbonate, $FeCO_3$, with iron content 20–30%.

Limonite and siderite are termed lean ores since they are so low in iron. The ore found in England in Lincolnshire, Northamptonshire, Leicestershire and Oxfordshire is one of low iron content and is generally obtained by opencast working.

Iron ore, as mined, contains appreciable amounts of earthy waste material known as gangue, and if this were fed into the furnace with the ore, more fuel would be consumed to heat it up and it would reduce the furnace capacity. Ores are washed, or magnetically separated in the case of the magnetic ores, to remove much of this waste material. They are roasted or calcined to drive off the moisture and carbon dioxide and to remove some of the sulphur by oxidation to sulphur dioxide, and crushed to bring the lumps to a more uniform size.

Agglomeration of ores

Finer particles of ores (fines) cannot be fed into the furnace because they would either be blown out or would seal up the spaces in the burden (coke, ore and flux) necessary for the passage of the blast. The smaller particles can be made to stick together or agglomerated either by sintering or pelletizing.

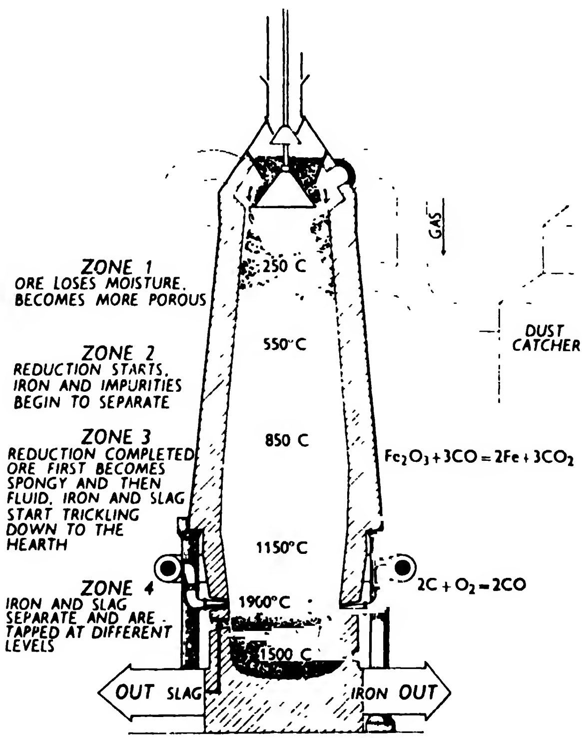
Sintering. The materials are chiefly iron ore fines, blast furnace flue dust, limestone and/or dolomite and coke breeze or fine anthracite as fuel. They are mixed, moistened and loaded on to a moving grate consisting of pallets through which air can circulate. The mixture is ignited by gas or oil jets and burns, sucking air through the bed. The sinter is tipped from the end of the moving gate, large lumps being broken up by a breaker.

Pelletizing. The ore is usually wet concentrates made into a thick slurry to which a small amount of bentonite is added. This is then balled by feeding it into a slowly rotating drum inclined at 5–10° to the horizontal. The green balls are then fed into a vertical shaft furnace or onto a travelling grate as in sintering where they are dried, fired and cooled.

The blast furnace

The furnace is a vertical steel stack lined with refractories. Charging is done at the top and pig iron and slag are tapped from the bottom (Fig. 2.1). Large volumes of gases (including carbon monoxide) are

Fig. 2.1 The blast furnace



evolved during operation of the furnace and are burnt in stoves which provide the heat to raise the temperature of the air blast to about 1350 °C. This reduces the amount of coke required because combustion speed is increased and thus efficiency is increased and there is a reduction in the sulphur content of the pig iron. Four-fifths of the air in the blast is nitrogen, which takes no part in the process yet has to be raised in temperature. By enriching the blast with oxygen (up to 30%) the nitrogen volume is reduced and the efficiency increased.

During the operation of the furnace the burning coke produces carbon monoxide, which reduces the ore to metal. This trickles down to the bottom of the furnace where the temperature is highest. The limestone is decomposed into lime (calcium oxide), which combines with the silica in the gangue to form a slag, calcium silicate, and the iron begins to take in carbon. Slag is tapped from the upper notches and pig iron from the lower (Fig. 2.1).

Blast furnaces in Europe, the United States and Japan are becoming increasingly larger with greater productivity. Modern furnaces can use oil fuel injection, top pressure, high blast temperatures, oxygen enrichment and pre-reduced burden in the quest for greater economy in energy and increased productivity.

Because of the large volume of these furnaces (4600 m^3) it is difficult to distribute the reducing gases evenly throughout the burden, so ore size is carefully graded, strong coke is used, and equalization is done by high-top-pressure nitrogen, which reduces the velocity of the gas in the lower regions of the furnace, keeping the gas in longer contact with the burden and allowing it to ascend more uniformly thus achieving more efficient reduction.

Furnace construction can be by the stack being welded on to a ring girder which is supported on four columns or there can be a free-standing stack within a structure of four columns. The refractories are carbon and carbon with graphite for the tuyères and hearth, and aluminium oxide (alumina) for the stack. Cooling is by forced-draught air or by water for the underhearth, and flat copper coolers or staves are used for the stack with open- or closed-circuit cooling water systems.

Typical burdens are 80% sinter, 20% ore or 60/40% sinter, 40/60% pellets; coke and burden are screened, weighed and delivered to the furnace on a charging conveyor, the charging system being either double bell or bell-less with a distribution chute. Furnace charging may be done automatically and can be fully computerized. The gas cleaning plant incorporates a dust catcher and water scrubber.

Direct reduction of iron ore

As alternatives to the blast furnace method of producing iron from its ore, other processes can be used, not dependent upon the use of coke. The ore is converted into metallized pellets or sponge iron by removing the oxygen from the iron to leave metallic iron. The amount of metallic iron produced from a given quantity of ore is termed the degree of metallization and is the ratio of the amount of metallic iron produced to the total iron in the ore. The iron left after the removal of the oxygen has a honeycomb structure and is often termed sponge iron.

Direct reduction (DR) processes may be classed according to the type of fuel used: either gaseous hydrocarbons using reduced gases produced by reforming from natural gas (methane); or solid fuel such as coal or coke breeze. The gaseous fuel type can be a vertical retort (Hyl), vertical shaft furnace (Midrex) or a fluidized bed (HIB) while the solid fuel type uses rotary hearths or kilns (SL RN, Krupp). A high degree of purity of ore is required for sponge iron because gangue is not removed at the iron-making stage but later in the steel-making process, so that the more gangue present, the less the efficiency of the process. At present pelletized concentrates are used but screened natural lump ore of similar purity can now be used as processing difficulties have been overcome.

Typical of the gaseous type of direct reduction plant installed by British Steel is the Midrex, using natural gas as the reductant. The natural gas is steam-reformed to produce carbon monoxide and hydrogen thus:

$$\begin{array}{ccccccc} \text{methane} & & \text{steam} & & & \text{carbon monoxide} & & \text{hydrogen} \\ CH_4 & + & H_2O & + & \text{heat} \rightarrow & CO & + & 3H_2. \end{array}$$

Other hydrocarbons such as naphtha or petroleum can also be used as reductants.

Considering haematite, Fe_2O_3, as the ore, the carbon monoxide and hydrogen which are both reducing gases act as follows on the ore, reducing it to metallic iron of spongy appearance, the reduction taking place above 800 C.

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2 + \text{heat (exothermic).}$$
$$Fe_2O_3 + 3H_2 + \text{heat} \rightarrow 2Fe + 3H_2O \text{ (endothermic).}$$

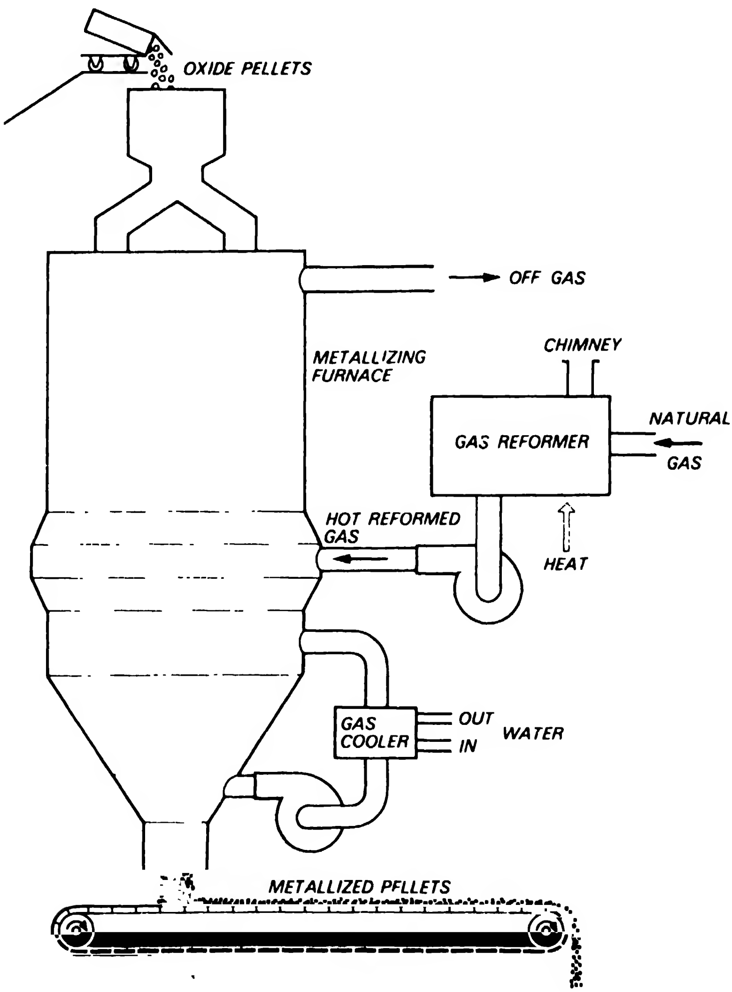
Cold oxide pellets are fed by successive additions into the top of the vertical shaft furnace up which flows a counter-current of heated reducing gas (carbon monoxide and hydrogen). Metallization occurs and the metallized pellets are taken from the bottom of the furnace so that the process is continuous and economical in labour, achieving a metallization of 92 95%, the off-gases being recovered and recycled (Fig. 2.2).

DR iron is used chiefly in the electric arc and basic oxygen furnaces and it is evident that the future of this gaseous type of reduction depends upon a continuing supply of natural gas at a price competitive with that of coke.

Cast iron

Pig iron from the blast furnace is not refined enough for making castings, so in the foundry the iron for casting is prepared as follows: a coke fire is lit at the bottom of the small blast furnace or cupola and then alternate layers of pig iron (broken up into pieces) and scrap and coke together with small quantities of limestone as flux (for purifying and deslagging) are added. When the mass has burnt up, the blast is turned on

Fig. 2.2. Direct reduction of iron ore by the Midrex process



and the molten iron (melting point 1130°C) flows to the bottom of the furnace from where it is tapped into ladles or moulds direct. Cast iron is relatively cheap to produce and its melt fluidity gives excellent casting properties. It is an alloy of many elements, and an average composition is: iron 95-98%, carbon 3-4%, silicon below 3%, sulphur below 0.2%, phosphorus below 0.75%, manganese below 1%.

The carbon exists in two forms: chemically combined carbon, and free carbon simply mixed with the iron and known as graphite. The grey look of a fracture of grey cast iron is due to this graphite, which may be from 3 to $3\frac{1}{2}$%, while the chemically combined carbon may range from 0.5 to 1.5%. As the amount of combined carbon increases, so do the hardness and brittleness increase, and if cast iron is cooled or chilled quickly from a very high temperature, the amount of combined carbon is increased, and the free carbon is reduced. As a result this type of cast iron is more brittle and harder than grey iron, and since it has a white appearance at a fractured surface, it is termed white cast iron. This has from 3 to 4% of carbon chemically combined.

Cast iron possesses very low ductility, and for this reason it presents difficulty in welding because of the strains set up by expansion and contraction tending to fracture it.

The properties of cast iron can be modified by the addition of other elements. Nickel gives a fine grain and reduces the tendency of thin sections to crack, while chromium gives a refined grain and greatly increases the resistance to wear The addition of magnesium enables the graphite normally present in flake form to be obtained in spheroidal form. This SG (spheroidal graphite) cast iron is more ductile than ordinary cast iron (see pp. 82-3).

Wrought iron

Wrought iron is now of historical interest only and is very difficult to obtain. It is manufactured from pig iron by the pudding process which removes impurities such as carbon, sulphur and phosphorus leaving nearly pure iron. A typical analysis is: iron 99.5-99.8%, carbon 0.01-0.03%, silicon 0-0.1%, phosphorus 0.04-0.2%, sulphur 0.02-0.04%, and manganese 0-0.25%.

When fractured, wrought iron shows a fibrous or layered structure but will bend well and is easily worked when hot. It does not harden on cooling rapidly and can be welded in the same way as mild steel.

Steel-making

Pig iron consists of iron together with 3-4% carbon, present either in the combined form as iron carbide or in the free form as graphite, the

composition depending upon the type of iron ore used. In addition it contains other elements, the chief of which are manganese, silicon, sulphur and phosphorus. By oxidation of the carbon and these other elements the iron is converted into steel, the composition of which will have the required carbon and manganese percentage with a very small amount of sulphur and phosphorus (e.g. sulphur 0.02% max. and phosphorus 0.03% max.) for a typical welding-quality steel. There are two processes in steel-making, acid and basic, and they differ in the type of slag produced and in the refractory furnace lining. In the acid process, low-sulphur and -phosphorus pig iron, rich in silicon, produces an acid slag (silica) and the furnace is lined with silica refractories to prevent reaction of the lining with the slag.

In the basic process, which is largely used nowadays, phosphorus-rich pig irons can be treated with lime (a base) added to the slag to reduce the phosphorus content, and the slag is now basic. The refractory lining of the furnace must now be of dolomite (CaO, MgO) or magnesite (MgO) to prevent reaction of the slag with the furnace lining. This basic process enables widely distributed ores, with high phosphorus and low silica content, to be used.

Much steel was formerly made by the Bessemer process (acid or basic), in which an air blast is blown through the charge of molten iron contained in a steel converter lined with refractories, oxidizing the impurities, with the exothermic reaction providing the necessary heat so that no external heat source is required. The large volume of nitrogen in the air blown through the charge wastes much heat and in addition nitrogen forms nitrides in the steel reducing the deep-drawing properties of the steel, so the process is now little used.

In the *Open Hearth* (acid or basic) process, now obsolete, the heat required to melt and work the charge is obtained from the burning of a producer gas-and-air mixture over the hearth. Both gas and air are heated to a high temperature (1200 C) by passing them through chambers of checkered brickwork in which brick and space alternate. In order that the process is continuous a regenerative system is used (Fig. 2.3). There are two sets of chambers each, for gas and air. While the gas and air are being heated in their passage through one pair of chambers, the high-temperature waste gases are pre-heating the other pair ready for the change-over. Pig iron and scrap are fed into the furnace by mechanical chargers, the pig iron being fed in the molten condition if the steel-making furnace is near the blast furnace as in integrated plants. The charging doors are on one side and the tapping hole on the other, the hearth capacity being 30–200 tonnes.

When the charge is molten, iron ore is added and oxidation takes place, carbon monoxide being formed, the carbon content of the melt is reduced

and silicon and manganese are also oxidized. Finally deoxidizers (ferromanganese, ferrosilicon, aluminium) are added just before tapping, or as the steel is run into the ladle, to improve the quality of the steel. Ferromanganese (80% Mn, 6% C, remainder iron) reacts with the iron oxide to give iron and manganous oxide, which is insoluble in steel, and the excess manganese together with the carbon adjusts the composition of the steel.

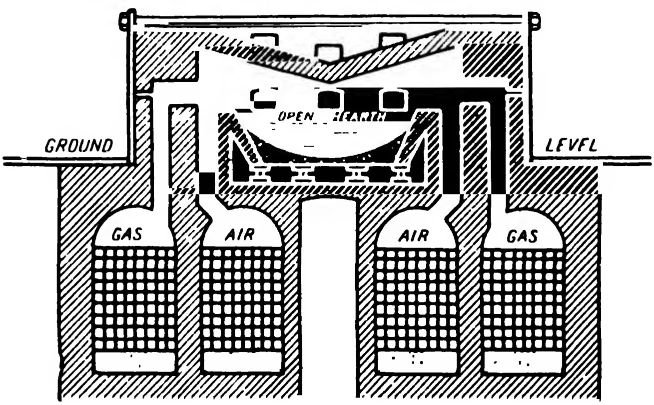
The acid process is now declining in use and the basic process produces normal grades of steel. The basic slag, rich in phosphorus, is used as a fertilizer.

Oxygen steel-making

With the introduction of the tonnage oxygen plant situated near the steel furnaces, oxygen is now available at competitive cost in large volumes to greatly speed up steel production. The oxygen plant liquefies air and the oxygen is then fractionally distilled from the nitrogen and argon and is stored in the liquid form as described in the section on liquid oxygen. In the open hearth process an oxygen lance is arranged to blow large volumes of oxygen onto the molten metal in the hearth. With the use of oxygen instead of air there is minimal nitrogen introduced into the steel (below 0.002%), so that its deep-drawing qualities are improved and the time for converting the charge into steel is reduced by as much as 50%. It appears that the basic open hearth process is being replaced by the basic oxygen furnace (BOF) in various forms in Britain, Europe, USA and Japan. The advantages are that iron ores of variable phosphorus content can be used and there are reduced labour and refractory costs. These factors together with the capability of the process to use up to 40% scrap make for reduced costs and higher efficiency.

When the oxygen is blown onto the molten charge it reacts to form iron

Fig 2 3



oxide, which combines with lime present as flux to form an oxidizing slag on the melt. Reactions occur between the molten metal and the slag resulting in the removal of phosphorus, and lowering of the silicon, manganese and carbon content.

Basic oxygen steel (BOS)

The *basic oxygen steel-making* process together with the electric arc process is responsible for much of present-day steel production. A typical basic oxygen furnace consists of a steel-cased converter lined with dolomite holding up to 400 tonnes of metal. Hot metal is transported in torpedo ladles to the hot-metal pouring station equipped with extraction facilities for fume and kish (graphite which separates from and floats on top of the charge), and selected torpedoes are desulphurized with calcium carbide. The hot pig iron, scrap, flux and any alloys are added and oxygen is injected through a multi-holed, water-cooled lance from a near-by tonnage oxygen plant, onto the surface of the charge. Oxidation is rapid, with the blowing time lasting about 17 minutes, and the converter is then tilted and emptied. The BOF takes between 25 and 35% of scrap metal and efforts are being made to increase this percentage because scrap is cheaper than hot pig iron (Fig. 2.4 *a,b,c,d,e*).

The Maxhütte bottom-blown furnace (OBM) is a steel-cased converter lined with dolomite with special tuyères in the base of the furnace through which oxygen and powdered lime are introduced. This in turn is surrounded by a protective shield of hydrocarbon fuel gas (natural gas, propane) to protect the refractory lining (Fig. 2.5). The remainder of the process is similar to that already described and the benefits claimed for this process are absence of fuming and splashing and a lower final carbon and sulphur content in the steel, the injection of lime ensuring rapid removal of the phosphorus.*

Electric arc steel-making

When a welder uses a carbon electrode to produce an arc and give a molten pool on a steel plate he is using the same basic principle as that which is done on a very much larger scale in the electric arc furnace. The heat in this type of furnace comes from the arcs struck between three carbon electrodes connected to a three-phase electric supply and the charge in the furnace hearth, and thus no electrode is required in the furnace hearth.

* Oxygen is used for both top and bottom blowing for decarbonization in the LD (Linz Donawitz) converter. In combined blowing an argon nitrogen mixture stirs and homogenizes the melt.

Fig. 2.4. Basic oxygen steel-making.
(*a*) Charging with scrap. The converter is tilted and charged with scrap from a charging box which tips the scrap into the previously heated converter. The scrap represents up to 30% of the total charge.

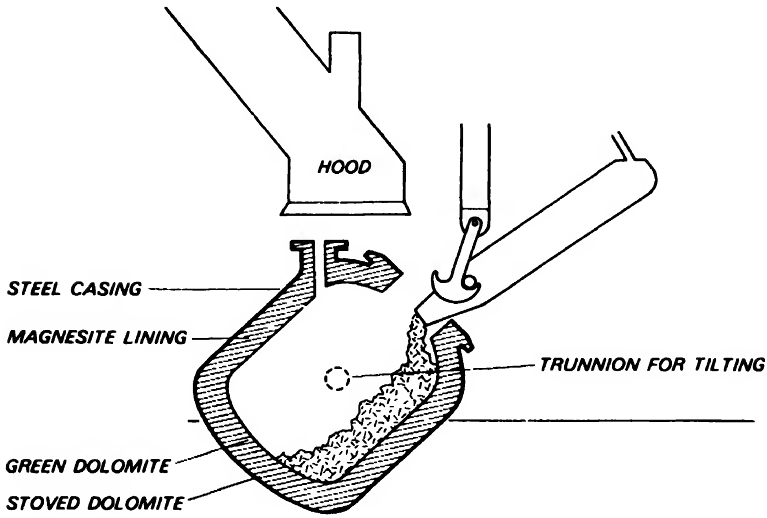
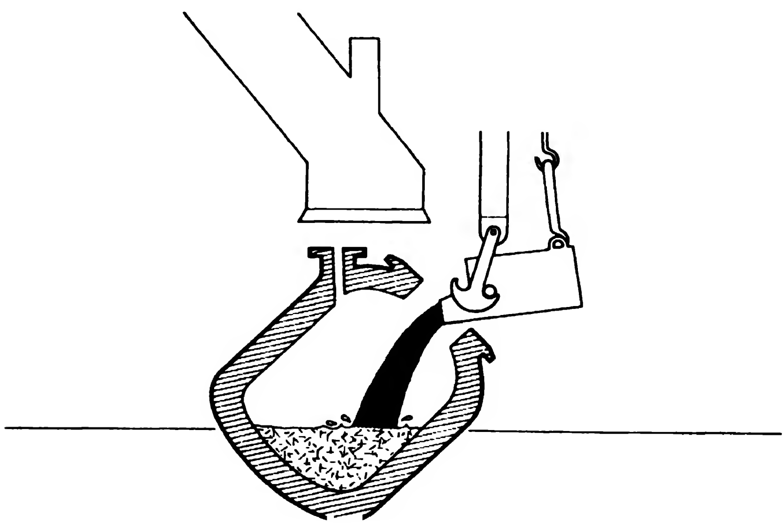
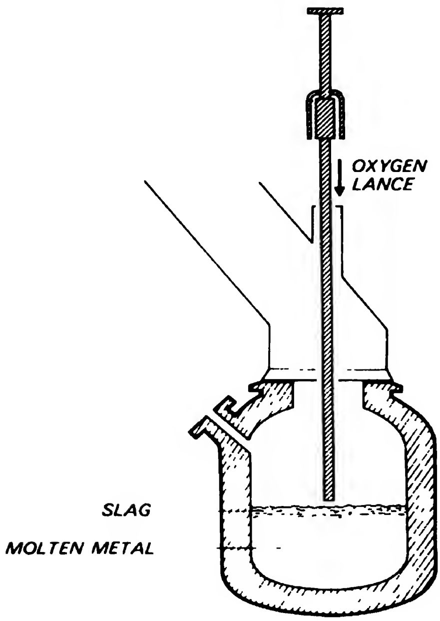


Fig. 2.4 (*b*) Charging with molten iron. Molten iron from the blast furnace is brought to the converter in 'torpedo-cars' and transferred by ladle into the converter.



(*c*) The fume-collecting hood is lowered on to the furnace neck. A water-cooled oxygen lance is lowered to within a metre or so of the molten metal surface. Oxygen is blown through the lance and causes turbulence and rise in temperature of the metal. Impurities are oxidized with the 'blow' lasting about fifteen minutes during which time temperatures are carefully controlled and analysis made of the molten metal.



(*d*) When temperature and metal analysis are satisfactory the hood is lifted, the converter tilted and the steel poured from below the slag which has formed into the teeming ladle from which it passes to the continuous casting plant and is cast into ingots

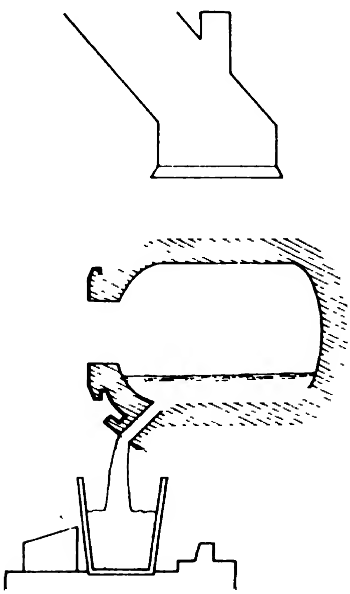


Fig 2.4. (*e*) Finally the converter is tilted in the opposite direction and the slag which remains is poured into a slag ladle

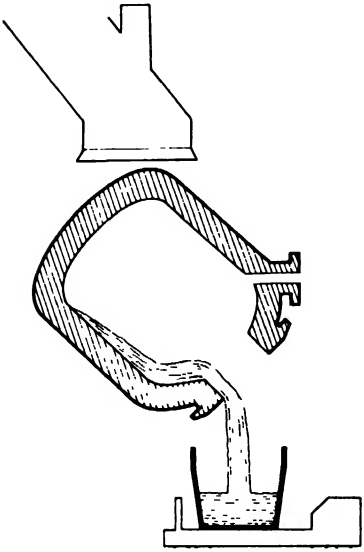
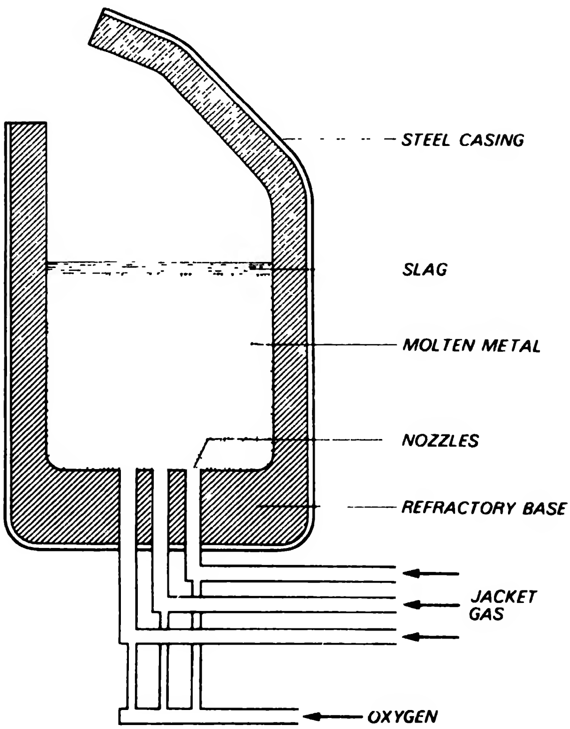


Fig 2.5. Maxhutte bottom-blown oxygen furnace (OBM)

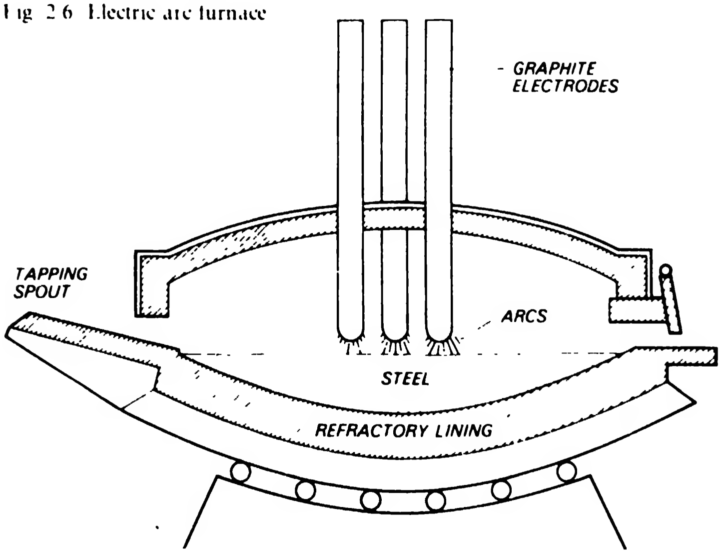


The furnace shell is mild steel lined with refractories, with two doors (one on smaller furnaces). The three electrodes project through the refractory-lined roof down to the level of the surface of the charge, and roof and electrodes are arranged to swing aside to clear the furnace shell for charging or repair, this type of furnace being batch-charged, though developments are proceeding to feed furnaces continuously either through the roof or side walls. A sealing ring on top of the side walls supports the weight of the roof and the furnace can tip about 15° towards the main door and about 50° forward for tapping. Some of the larger furnaces can also rotate so as to give a variety of melting positions for the electrodes (Fig. 2.6).

Since it is necessary to remove phosphorus and sulphur a basic slag is required, and the furnace must be lined with basic refractories such as dolomite or magnesite for roof, side walls and hearth to give the basic electric arc process. The acid process is only used in cases where melting only is to be done, with little refining.

Large transformers of the order of 80–100 MVA capacity feed from the grid supply to that for the arcs. The voltage drop across the arc is a function of the arc length, and the greater the voltage drop, the greater the power for a given arc current. As a result the secondary voltage to the arc may be 100–600 V, with currents up to 80 000 A in large furnaces. The three graphite electrodes can vary from 75 to 600 mm in diameter and in length from 1.2 to 2.5 m, and can be raised or lowered either hydraulically or by electric motor, this operation being done automatically so as to keep the arc length correct. Current to the electrodes is taken via water-cooled clamps and bundles of cables to give flexibility.

Fig. 2.6 Electric arc furnace



One of the greatest advantages of the arc furnace is that it can deal with up to 100% scrap charge, and whereas in the past it was used for making high-grade alloy steel it is now used to melt high-percentage scrap charges and even to produce ordinary grades of steel.

The charge is of scrap, iron ore, blast furnace iron, DR iron and limestone, depending upon availability. The electrodes are lowered onto the charge, the arcs struck and melting proceeds. The oxygen necessary for the removal of impurities is obtained from the iron ore charge, the furnace atmosphere and in many cases by lance injection of oxygen, the silicon, manganese and phosphorus being removed by oxidation and entering the slag. The carbon is oxidized to carbon monoxide, which burns to carbon dioxide.

Melting is done under a basic oxidizing slag, black in colour, and when the desired level of carbon and phosphorus is obtained, the slag is thoroughly removed and the melt deoxidized with ferrosilicon or aluminium. A reducing slag is now made using lime and anthracite or coke dust and the lime reacts with the iron sulphide to form calcium sulphite and iron oxide; the calcium sulphite is insoluble in steel and thus enters the slag, removing the sulphur. This removal requires reducing conditions in the furnace, which is not possible with any other furnace in which oxygen is used to burn the fuel so that this sulphur removal is another great advantage of the arc furnace. Alloy additions are made under non-oxidizing conditions which give good mixing, and carbon can be added if required (recarburation) in the form of graphite or coke.

Vacuum refining

Further improvement in steel quality is obtained by vacuum refining. An example is Vacuum Oxygen Decarburization (VOD). A stream of oxygen from a lance is blown onto the surface of the molten steel under partial vacuum in a vacuum chamber. Argon is bubbled through the melt for stirring and alloy additions are made from the top. With this method the carbon content of the steel can be reduced to 0.08% (and lower with higher vacuum), hydrogen and nitrogen contents are reduced and chromium addition recoveries are high.

Induction furnaces

These are melting furnaces generally used for the production of special steels in sizes from 100 to 10 000 kg and give accurate control over the steel specification (Fig. 2.7).

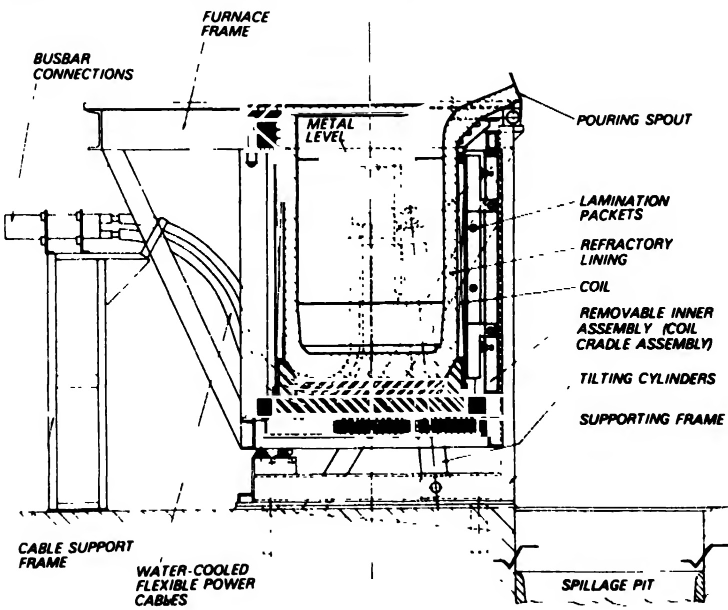
When discussing the principle of the transformer we will see (p. 219) that if an alternating current flows in the primary winding, an alternating

current is generated in the secondary winding. The alternating magnetic flux due to the primary current generates, or induces, a current in the secondary circuit. In the induction furnace the primary coil is wound around the refractory crucible which contains the metallic charge to be melted. When an alternating current flows in the primary coil eddy currents are induced in the charge and generate the heat required for melting. As the frequency of the alternating current increases, the eddy currents, and thus the heating effect, increase.

Furnaces operate at mains frequency (50 Hz) or at 100, 150, 800, 1600 Hz, etc., and high-frequency furnaces employing static converters to change the frequency operate from 10 to 15 kHz and at voltages up to several kV. The eddy currents produce a stirring action which greatly improves temperature control.

The furnace refractories can be a pre-cast crucible for the smaller furnaces or have a rammed lining of magnesite or, in some cases, silica. The hollow square-shaped copper conductors of the coil are closely wound and water-cooled, this being an essential feature to prevent overheating and consequent breakdown. Small furnaces up to 50 kW are very convenient for laboratory and research work and can have capacities as low as a few kilograms. Clean scrap of known analysis can be used in the charge, and as oxidation losses are minimal and there is little slag, there is practically no loss of alloying elements during the melt.

Fig. 2 7 Typical coreless induction furnace in capacities of 0.75–10 tonnes.



Malleable cast iron

This is made from white cast iron by annealing or graphitizing. The white cast iron is packed in haematite, heated to about 900 °C and kept at this for two or three days, after which the temperature is slowly reduced. In this way, some of the combined carbon of the white cast iron is transformed into free carbon or graphite. Malleable castings are used where strength, ductility and resistance to shock are important, and they can be easily machined.

The 'blackheart' process is similar to the Réaumur or 'whiteheart' process just described except that bone dust, sand and burnt clay are used for packing in place of iron oxide, the temperature being about 850 °C. This converts the combined carbon in the cast iron into temper carbon, and after the treatment they contain little or no combined carbon and about $2\frac{1}{2}\%$ graphite. The castings prepared by the former method show a grey fractured surface with a fine grain like mild steel, while those made by the 'blackheart' process have a black fracture with a distinct white rim.

A typical composition of malleable iron is: carbon 2–3%, silicon 0.6–1.2%, manganese under 0.25%, phosphorus under 0.1%, sulphur 0.5–0.25%.

The effect of the addition of carbon to pure iron

We have seen that the chief difference between iron and mild steel is the amount of carbon present. Steel may contain from 0.03 to 2% carbon, mild or soft steel containing about 0.1% carbon and very hard razor-temper steel 1.7–1.9%.

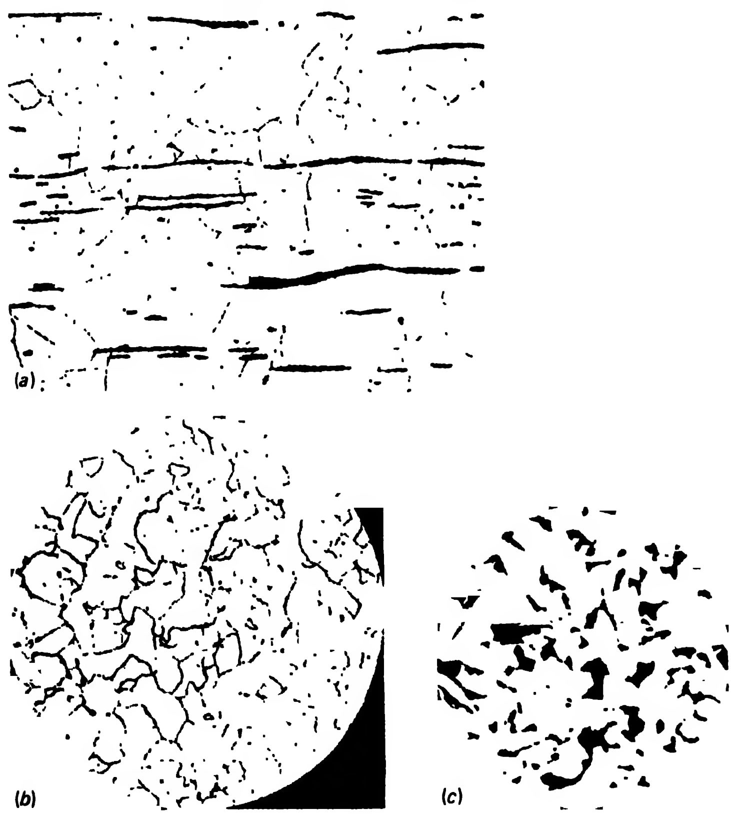
The composition of steel is therefore complicated by these variations of carbon content, and is rendered even more so by the addition of other elements such as nickel, chromium and manganese to produce alloy steels.

Let us consider the structures present in steels of various carbon contents which have been cooled out slowly to room temperature. If we examine a highly polished specimen of wrought iron under a microscope magnifying about 100 times (× 100), Fig. 2.8*a*, we can see the white crystals of ferrite with the crystal boundaries and also dark elongated bands, which are particles of slag entrapped during the rolling process. A specimen with no inclusions is shown in Fig. 2.8*b*. Now examine a specimen of 0.2% carbon steel under the same magnification. It shows dark areas in with the whiter ferrite, Fig. 2.8*c*. A 0.4% carbon steel appears with more dark areas, Fig. 2.9*c*, so that it is evident that an increase in carbon content produces an increase in these dark areas, which if observed under first a magnification of × 1000, Fig. 2.9*a*, and then of × 2500, Fig. 2.9*b*, are seen

to consist of a layered structure, darker areas alternating with lighter ones. The dark areas are iron carbide (Fe_3C) or cementite formed by the chemical combination of ferrite and carbon thus: ferrite + carbon → cementite, or iron + carbon → iron carbide. These alternating layers of ferrite and cementite are called pearlite since they have a mother-of-pearl sheen when illuminated. Pearlite contains 0.85% carbon and is known as a eutectoid.* When a steel contains 0.85% carbon the structure is all pearlite and if more than this percentage is present we find that the carbon has combined with more ferrite reducing the area of pearlite and forming cementite in the structure. Pearlite is a ductile structure while cementite is hard and brittle so that as the carbon content increases above 0.85% and more cementite is formed, the steels become very hard and brittle and steels of more than

* See Chapter 3, eutectoid change

Fig. 2.8
(*a*) Wrought iron, showing grains of ferrite and slag inclusions. × 100
(*b*) Ferrite × 100
(*c*) 0.2% carbon steel forging normalized, showing pearlite and ferrite × 100.

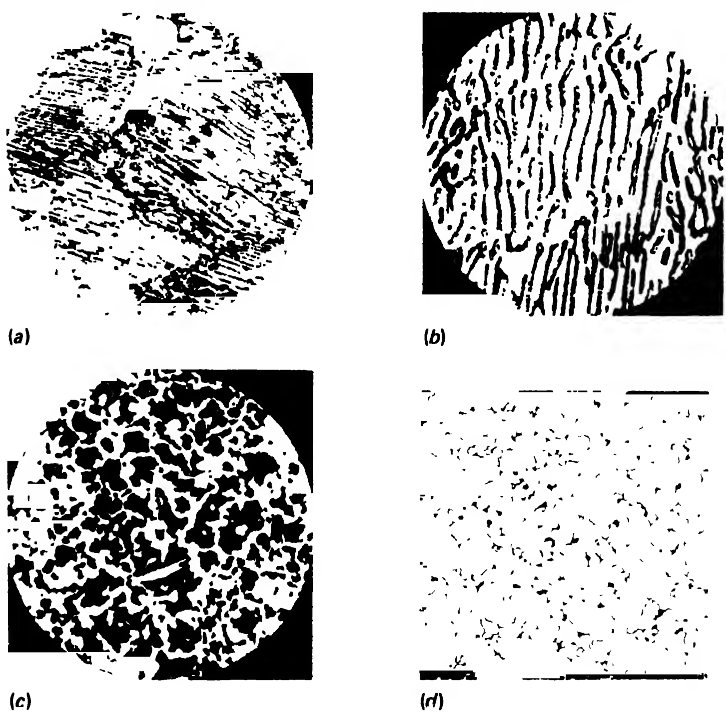


1.7–1.8% carbon are rarely encountered (Fig. 2.9*d* and Fig. 2.10). Above 2% the carbon may be present as free carbon, termed graphite, and when the carbon percentage of the iron is between 2½% and 4% it is known as cast iron. In grey cast iron, which is soft and machinable (but brittle), the carbon is present in the free state as graphite but rapid cooling can cause the carbon to be in the combined form as cementite when we have white cast iron, which is hard and not machinable. Hence in a steel the carbon is always in the combined form while in cast iron it may be present either free as graphite or in the combined form as cementite (Fig. 2.11).

SG cast iron

The flakes of graphite present in grey cast iron which reduce its tensile strength can be changed to sphere-shaped particles by adding to the molten iron small amounts of magnesium (or various other substances). This spheroidal graphite (SG) cast iron has greatly increased strength and

Fig. 2.9
(*a*) 0.8% carbon steel, annealed. × 1000.
(*b*) 0.8% carbon tool steel, annealed. × 2500.
(*c*) 0.4% carbon steel forging, annealed. × 100.
(*d*) Cementite structure in 1.2% carbon tool steel, normalized. × 100.



ductility. In the 'as cast' condition the matrix is normally pearlite, with the carbon in the combined form, and is hard, with a tensile strength about twice that of grey cast iron. Normalizing improves its mechanical properties, and stress-relief heat treatment at 550°C is recommended for more complicated castings. Annealing the SG iron gives a ferritic matrix, lowering the tensile strength but improving ductility and elongation compared with pearlitic iron. The iron can be hardened by quenching and tempering, and addition of 1–2% nickel increases its hardenability. Nominal composition: C 3.5–3.8%, Si 1.8–2.5%, Mn 0.2–0.6%, P 0.05%, Ni 0–2.0%, Mg 0.04–0.07%.

Carbon and carbon–manganese steels

As the carbon content of a steel increases from 0.05% to about 1.1% the steel changes from a low carbon, soft and malleable steel to a high carbon steel which when heat treated is hard and brittle. Between these values there are a great number of steels suitable for various purposes. All

Fig 2.10 Structure of steels with varying carbon content

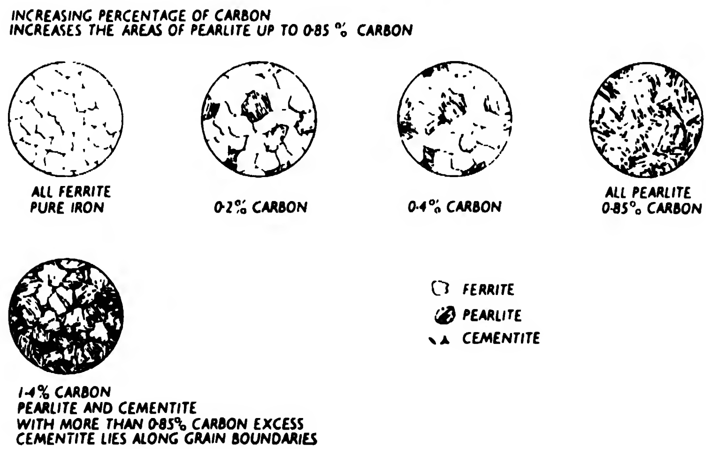
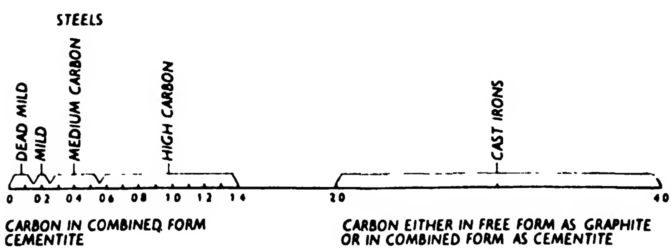


Fig. 2.11



Examples: carbon and carbon–manganese steel. BS 970 Part 1

Steel specification	Nearest AISI/SAE Eqvt.	Type	Application	C%	Mn%
030A04	1006	low carbon	pressings and screws	0.08	0.2–0.4
040A12		low carbon	cold forming steel	0.10–0.15	0.3–0.5
040A17		low carbon	cold forming steel	0.15–0.20	0.3–0.5
070M20	1021/1022	20 carbon	general purpose mild steel	0.16–0.24	0.5–0.9
080A30	1030	30 carbon	pipes, valves, flanges	0.28–0.33	0.7–0.9
080A35	1034/1035	35 carbon	high tensile shafts and forgings	0.33–0.38	0.7–0.9
070M55	1055	55 carbon	crankshafts	0.50–0.60	0.5–0.9
060A62	1059	62 carbon	induction hardened gears	0.60–0.65	0.5–0.7
080A72	1070	72 carbon	spring steel	0.70–0.75	0.7–0.9
120M19		19 carbon 1.2 manganese	welded structures	0.15–0.23	1.0–1.4
150M28		28 carbon 1.5 manganese	welded structures	0.24–0.32	1.3–1.7

In the above, sulphur and phosphorus below 0.050%.
AISI = American Iron and Steel Institute, SAE = Society of Automotive Engineers.

steels contain some manganese from the deoxidation process and below 1% it is not considered as an alloying element. If, however, the percentage is increased to about 1.5 we have a range of carbon–manganese steels which have increased tensile strength and are suitable for welded structures.

The designation of these steels (BS 970 Part 1) uses six digits, the first three being from 000 to 299. The plain carbon and carbon-manganese steels fall in the range 000 to 199 and these figures represent 100 times a mean manganese content. These digits are followed by a letter (A, H or M), the steel being supplied to: A, analysis; H, hardenability requirements; and M, mechanical properties. The fifth and sixth digits represent 100 times the carbon content of the steel thus:

> ***Example.*** 040A12 manganese content 0.3–0.5%; A, supplied to analysis; carbon content 0.1–0.15%. This is a cold forming steel.

The free cutting steels fall within the range 200–240 and the second and third digits indicate 100 times the minimum or mean sulphur content.

The table (p. 84) gives examples of some of the steels and for these the maximum sulphur and phosphorus content is 0.05% in each case. Phosphorus makes the steels cold short (liable to cracking when cold worked). Sulphur makes the steels hot short (liable to cracking when hot worked) hence the very low maximum allowance. The increased sulphur content in the free cutting steels (sulphur up to 0.6% maximum and phosphorus up to 0.07% maximum) improves the machinability but they are difficult to weld and many are not satisfactorily welded.

Alloy steels

An alloy steel may be defined as a steel which owes its properties to the presence of elements other than carbon, manganese up to 1.1% and silicon up to 0.5%.

The purpose of the alloying elements is to give the steel a distinct property which in every case is to increase its toughness, hardness or tensile strength, and to give cleaner and more wear-resistant castings.

Low alloy steels include: (1) structural steels; (2) creep-resistant steels; and (3) high tensile low-alloy steels.

Pre-heating to 150–200 °C according to type is usually required when welding these last steels.

The chief elements which are alloyed with steel are nickel, chromium, manganese (above 1.1% molybdenum, tungsten, vanadium, copper and silicon. We shall only consider very briefly the effect produced on the steel

by the alloying elements and not attempt to discuss the variety of steels available under each heading.

Nickel steels

The addition of nickel to a steel increases the strength and toughness. The nickel lowers the critical cooling rate and tends to decompose carbides present to form graphite so that plain nickel steels usually have a lower carbon content. For the higher carbon content nickel steels, manganese, which stabilizes the carbides, is generally added. Nickel tends to form austenite, refines the grain and limits grain growth and gives a range of steels suitable for highly stressed parts such as crankshafts, and axle shafts. The addition of 36% nickel gives a steel with a very low coefficient of thermal expansion.

Examples of direct hardening steels containing nickel. BS 970 Part 2

Steel specification	Application	C %	Si %	Mn %	S%	P%
503M40	crankshafts	0.36 0.44	0.10–0.35	0.70 1.00	0–0.5	0–0.40
503H37		0.33-0.41	0.10 0.35	0.65-1.05	0–0.50	0–0.40

Chromium steels and nickel-chromium (stainless) steels

Chromium has the opposite effect from nickel on steel because it raises the upper critical temperature, tends to form ferrite, and, due to the formation of carbides, it increases the hardness and strength but reduces the ductility and promotes grain growth. Overheating and maintaining at elevated temperature for too long a period should thus be avoided.

When greater amounts of chromium are added the steel becomes resistant to corrosion, a thin layer of resistant chromium oxide forming on the surface.

Examples of direct hardening steels containing chromium. BS 970 Part 2

Steel specification	Applications	C %	Si %	Mn %	Cr %	S %	P %
530A30	gears and connecting rods	0.28 0.33	0 10-0.35	0.60 0 80	0.90 1.20	0-0.50	0-0.40
530/H36		0.33 0.40	0.10-0.35	0.50-0.90	0.80 1.25	0 0.50	0-0.40

If the steel contains about 11% chromium it may be termed stainless and it is convenient to consider four groups: A, martensitic; B, ferritic; C, austenitic; and D, duplex. There are also specialized stainless steels for special applications.

Group A: Martensitic. These steels are alloyed mainly with chromium, 11–18%, and harden upon cooling from welding temperatures, resulting in embrittlement and a tendency to crack in the weld and heat-affected zone so that in general they are not recommended for welding. These steels are hardenable by heat treatment, are magnetic and have a lower coefficient of expansion and a lower thermal conductivity than mild steel. They are used in engineering plant subject to mildly corrosive conditions, for cutlery, sharp-edged instruments, ball and roller bearings, etc., according to the carbon and chromium content.

If welding is to be carried out the work should be pre-heated to 200–400 °C, followed by slow cooling after welding to reduce the hardness and danger of cracking. Post-heating to 650–700 °C is also advised and a basic electrode of the 19% Cr, 9% Ni, 3% Mo type is used. Electrodes of similar composition to the parent metal are used only for limited applications such as overlaying.

Examples of this class of steels are:

C%	Cr%	Si%	Mn%	Other elements	Weldability
0.28–0.36	12–14	0.8	1.0	—	Not generally recommended
0.12	11.5–13.5	0.8	1.0	—	Poor brittle welds but type with 0.06% C max., fair.
0.7–0.9	15.5–17.5	0.8	1.0	0.3–0.7 Mo	Poor. Should not be welded.

Group B: Ferritic. These steels are alloyed with chromium and because of their low carbon content the structure is almost completely ferritic. They are magnetic and though easier to weld than the martensitic group because they are not hardenable to any extent by heat treatment, they suffer from grain growth and embrittlement at temperatures above 900 °C, and from a form of intergranular corrosion in the HAZ.

When welding these steels pre-heating to 200 °C is recommended followed by post-heat at 750 °C, which helps to restore ductility. An austenitic stainless steel electrode is recommended for mildly corrosive conditions but if the application is in sulphur-bearing atmospheres these attack the nickel. An example of this ferritic type is: C 0.08%, Cr 16–18%, Si 0.8%, Mn 1.0%. Weldability is fair, but welds tend to be brittle.

Group C: Austenitic. These steels are alloyed with chromium and nickel. The presence of nickel makes the steel austenitic at room temperature, confers high temperature strength, helps corrosion resistance and controls the grain growth associated with the addition of chromium. The chromium tends to form carbides while the nickel tends to decompose them, so that in this group of steels the disadvantages of each alloying element are reduced. The addition of molybdenum to these steels is to improve corrosion resistance and high-temperature strength. (Temper brittleness may occur when the steels are tempered in the range 250–400 °C.) It is the high-nickel, high-chromium steels which are of great importance in welding since much fabrication is done in these steels.

Those steels containing 17.5–19.5% chromium and 8–10% nickel, known as 18/8 from their nearness to this composition, harden with cold work, are non-magnetic, resistant to corrosion, can be polished, machined and cold-worked. They have a coefficient of thermal expansion 50% greater than mild steel but the thermal conductivity is much less than mild steel so that there is a narrower HAZ when they are welded. They are used in chemical, food, textile and other industrial plant subject to corrosive attack, also for domestic appliances and decorative applications.

Group D: Duplex. These steels have a structure of austenite and ferrite, the ferritic content being of the order of 35–75%, with a carbon content of 0.03–0.25% and up to 3% molybdenum. If nitrogen is added, say up to 0.14%, resistance to pitting is improved (see steel number 329 in the table on p. 92). These steels have a high resistance to corrosion and cracking, with a high strength/weight ratio. They are becoming increasingly used for chemical plant and gas and oil pipe-lines, and also in the 'off shore' industry.

Other types of stainless steels. Nitric acid grade (NAG) steel is used where high resistance to nitric acid is important. Steel number 304 L can be used, but with a lower carbon content of about 0.015% and practically no boron. Both molybdenum and nitrogen are added to improve resistance to corrosion and to increase mechanical strength. Their presence is indicated by the letters M and N after the grade of steel. Iron chromium alloys may have some aluminium added to them (e.g. alloy number 405 has about 0.2% added). This forms aluminium oxide (Al_2O_3) on the surface of the alloy and prevents further corrosion.

Weld decay

When the austenitic steels are heated within the range 600–850 °C, carbon is absorbed by the chromium and chromium carbide is precipitated along the grain boundaries (Fig. 2.12). As a result, the chromium content of

the austenite in the adjacent areas is reduced and hence the resistance to corrosive attack is lowered. When welding, a zone of this temperature range exists near the weld and runs parallel to it, and it is in this zone that the corrosion may occur and is known as weld decay, though no corrosive effect occurs in the weld itself. Heat treatment, consisting of heating the part to 1100 °C and water quenching, restores the carbon to solid solution but has the great drawback that much of the fabricated work is too large for heat treatment.

The difficulty is overcome by adding small quantities of titanium, niobium (columbium) or molybdenum to the steel. These elements form carbides very easily and thus no carbon is available for the chromium to form carbides. The austenitic steels with these additions are known as stabilized steels and they contain a very low percentage of carbon (0.03–0.1%). They have good welding properties and need no subsequent heat treatment. The steels with 0.03% carbon may have no stabilizers added but are suitable for welding because the low carbon content precludes the formation of carbides, so that modern low carbon steels do not suffer from weld decay.

Electrodes of 18% Cr–8% Ni; 19% Cr–10% Ni; and 25% Cr–12% Ni, with or without Mo, Nb, Ti and W produce welds which contain residual ferrite and are resistant to hot cracking when the welds are under restraint. Grades with a higher ferrite content under certain conditions in the temperature range 450–900 °C may lose ductility and impact resistance due to the transformation of ferrite into the brittle sigma phase. Most stainless steels however do not encounter these conditions and thus embrittlement does not occur. Manufacturers often indicate the ferrite percentage, e.g. 19% Cr, 9% Ni, 0.05–0.08% C, Nb 10 × carbon content, ferrite 6%.

Fig. 2.12 (*a*) Carbide precipitation at the grain boundaries in an 18/8 class stainless steel. The steel is in a state of heat treatment (500–900 °C) in which it is susceptible to intercrystalline corrosion, but it has not yet been subjected to a severe corrosive medium ×200 (*b*) Occurrence of intercrystalline corrosion in an 18/8 stainless steel strip. The steel is in the same condition as (*a*), but it has now been subjected to a severe corroding medium ×50

(*a*) (*b*)

When welding stainless steel to mild or low-alloy steel, dilution (pp. 111–13) occurs and the weld may suffer 20–50 % dilution. Root runs in butt joints are greatly affected since the weld metal is in contact with parent metal on both sides. Additional runs are partly in contact with weld metal already laid down and so suffer less dilution.

If a mild or low-alloy steel electrode is used for welding stainless steel to mild or low-alloy steel the weld metal will pick up about 5% Cr and 4% Ni from the stainless steel plate, giving a hardenable, crack-sensitive weld.

An austenitic steel electrode should be selected such that the weld metal will contain not less than 17% Cr and 7% Ni, otherwise there may not be enough ferrite present to prevent subsequent cracking. Electrodes of 20% Cr, 9% Ni, 3% Mo; or 23% Cr, 12% Ni are the most suitable, since their composition ensures that they accommodate the effects of dilution and there is a sufficiently high ferrite content to give resistance to hot cracking. Electrodes of 20% Cr, 20% Ni are also suitable, except for conditions of high restraint.

If mild steel fittings are to be welded to the exterior of stainless vessels, stainless pads can be first welded to the vessel and the fittings welded to the pads. This reduces the danger of penetration of diluted metal to the face subject to corrosive conditions.

BS 2926* covers the range of chromium nickel austenitic steels and the chromium steels. The code of composition is : first figure or figures is the chromium content, the second the nickel content and the third the molybdenum content. Nb indicates niobium stabilized, L is the low carbon type and W indicates the presence of tungsten. R is rutile coating (usually a.c. or d.c.) and B is a basic coating generally d.c. only, electrode +ve.

> ***Example.*** 19.12.3.L.R. is a 19% Cr, 12% Ni, 3% Mo low carbon (0.03%) rutile-coated electrode.

Identification of stainless and low-alloy steel

If a spot of 30% commercial concentrated nitric acid is placed on grease-free stainless steel, there is no reaction, but on low-alloy or plain carbon steel there is a bubbling reaction.

To determine to which group of stainless steel a specimen belongs, a hand magnet can be used. Ferritic and martensitic steels are strongly magnetic, whilst austenitic steels are generally non-magnetic. However the austenitic steels become somewhat magnetic when cold worked, but there is

* The AISI (American Institute of Steel and Iron) numbering system is used in the table on p. 92. The UNS (Unified Numbering System) is obtained from the AISI number by prefixing the number with the letter S and adding two digits to the end. The last two digits indicate additions to the steel. Thus AISI 316 is UNS S 31600, AISI 316 L is UNS S 31603. L indicates the low carbon variety of steel, with 0.03% C.

considerable difference in magnetic properties between them and the ferritic and martensitic types, which is easily detected. The identification of the various grades within the groups is not easy without laboratory facilities, but an indication is given by the hardness after heat treatment, which varies from 400 HV for a 0.12% C type to 700 HV for a 0.7–0.9% C type.

Students wishing to study further the metallurgical aspects of stainless steels should consult the Shaeffler's diagram on p. 411. In this the various alloying elements are expressed in terms of nickel, which is austenite-forming, and chromium, which tends to form ferrite. Using these values in conjunction with the diagram, information can be obtained on the possible behaviour of the steel during welding.

Steel containing molybdenum

Addition of 0.15–0.3% molybdenum to low-nickel and low-chrome steels reduces the tendency to temper brittleness and gives high impact strength. It increases the strength and creep resistance at elevated temperatures and increases the resistance to corrosion of stainless steels. The nickel chrome–molybdenum steels have high strength combined with good ductility and are used for all applications in engine components such as shafts and gears involving high stress.

Steel containing vanadium

Vanadium reduces grain growth and, due to the formation of its carbide which can be taken into solid solution, gives strength and resistance to fatigue at elevated temperatures. It is usually used in conjunction with niobium and chromium and in many ways these steels resemble the nickel-chromium steels.

C %	Mn %	Si %	Cr %	Mo %	V %	
0.45	0.6	0.25	1.25		0.15 min.	Spring steel.
0.13	1.4	0.25	0.6	0.3	0.1	

Manganese steel

Manganese, in the form of ferromanganese, is used for deoxidation of steel and in most steel there is a manganese content usually less than 1%. Above this value it may be considered an alloying element and lowers the critical temperature. The most widely used manganese steel is that containing 12–14% Mn and 1.2% C. This is austenitic but it hardens greatly with cold work and is widely used for components subject to wear and abrasion since the core retains its toughness while the surface layers harden with cold work to an intense degree. These steels have a wide range of applications in earth-moving equipment, rolls, dredger bucket lips and cases where resistance to wear and abrasion is of paramount importance.

Types of stainless and heat resistant steels

AISI number	Type	Composition (%)	Typical applications
302	Austenitic	C 0.15, Cr 18.0/19.0, Ni 8.0/10.0, Mn 2.0	Water tubing, sinks, trims, exhaust parts
304*	Austenitic	C 0.08, Cr 18.0/20.0, Ni 8.0/10.0, Mn 2.0	Food and dairy processing equipment, sinks, hollow ware
304L	Austenitic	C 0.03, Cr 18.4/20.0, Ni 8.0/10.5, Mn 2.0	Process plant, storage tanks
310	Austenitic	C 0.25, Cr 24.0/26.0, Ni 19.0/22.0, Mn 2.0	Furnace parts, heat exchangers, annealing covers
316*	Austenitic	C 0.08, Cr 16.0/18.0, Ni 10.0/14.0, Mn 2.0	Pulp and paper equipment, architectural uses
316L	Austenitic	C 0.03, Cr 16.0/18.0, Ni 10.0/14.0, Mn 2.0, Mo 2.0/3.0	Process plant parts in thick sections
317	Austenitic	C 0.08, Cr 18.0/20.0, Ni 11.0/15.0, Mn 2.0, Mo 3.0/4.0	As above, but with greater mechanical strength
321	Austenitic	C 0.08, Cr 17.0/19.0, Ni 9.0/12.0, Mn 2.0, Ti 5 × C content	Heater elements, furnace parts
329	Duplex	C 0.1, Cr 25.0/30.0, Ni 3.0/6.0, Mn 2.0, Mo 1.0/2.0, N_2 often added for corrosion resistance	All types of chemical plant and pipe-lines
405†	Ferritic	C 0.08, Cr 11.5/14.5, Mn 1.0, Al 0.1/0.3	All types of chemical plant and petroleum cracking parts
410	Ferritic	C 0.15, Cr 11.5/13.5	Pump parts, gas turbine parts, general engineering components
430	Ferritic	C 0.1, Cr 16.0/18.0, Mn 1.0	Stainless iron. Decorative household and vehicle trim

* Types 304 and 316 may have nitrogen added to increase both tensile and yield properties.

† The aluminium added improves high temperature corrosion properties.

Steel containing tungsten

Tungsten reduces the tendency to grain growth, raises the upper critical temperature, forms very hard, stable carbides which remain in solution after oil quenching and renders the steel very hard and suitable for cutting tools and gauges.

High-speed steel usually contains tungsten, chromium, vanadium, molybdenum and cobalt with a carbon content of 0.6–1.5%. Tungsten carbide, made by the sintering process, is used for tool tips for cutting tools, is extremely hard and brittle, and is brazed onto a carbon or alloy steel shank.

Nitralloy steels

These steels contain silicon, manganese, nickel, chromium, molybdenum and aluminium in varying proportion, and their carbon content varies from 0.2 to 0.55%. They are eminently suited for purposes where great resistance to wear is required. After being hardened, by the process of nitriding or nitrogen hardening them, they have an intensely glass hard surface and are suitable in this state for crankshafts, camshafts, pump spindles, shackle bolts, etc. (see Heat Treatment).

Composition of core wire and coverings for low-alloy steel electrodes

Most alloy steel MMA electrodes have a core wire based on a rimming steel (steel that has not been completely deoxidized before casting) and the alloying elements are added to the covering, e.g. those up to 9% chromium and also those of 12 14% manganese.

If the thickness of the coverings should make these electrodes difficult to use, as for example in pipe welding or other positional use, the core wire can be alloy steel, e.g. 1% Cr, 0.5% Mo; 2% Cr, 0.5% Mo; 5% Cr, 1% Mo.

The core wire of a stainless steel electrode is generally based on a wire of 1% Cr, 8% Ni. If more alloying elements are required they are added to the covering to produce a wide range of low-alloy steel electrodes such as 25% Cr, 12% Ni; 19% Cr, 9% Ni, 3% Mo; 23% Cr, 12% Ni, 2% Mo. (Note that the alloy content of the electrode and covering may be somewhat greater than that of the similar alloy steel to be welded to allow for some loss in the arc.)

If high deposition rates are required, the core wire can be of a mild steel base with the alloying elements added to the covering. Damage to the covering, however, results in a weld deposit which does not have

maximum corrosion resistance and should be used only in non-critical conditions.

Carbon equivalent

As the carbon content and the amount of alloying elements increases, care has to be taken, when welding these steels, of their tendency to crack. As there is a great variety of these steels it is convenient to express the carbon content and the percentage of each alloying element in terms of the 'carbon equivalent' of the steel. In this way the alloy steel is expressed in terms of a 'carbon content' and the formula used is BS 4360. The CE is thus an indication of the tendency to crack when welded.

$$CE\% = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

For weldable structural steels the CE is specified and the electrode manufacturers charts should be studied as to which electrode and which type of coating (basic or rutile) is suitable. In general, for high-tensile requirements with higher impact properties basic coated electrodes are advised. (See p. 421 for a worked example.)

The effect of heat on the structure of steel

Suppose we heat a piece of steel containing a small percentage of carbon and measure its temperature rise. We find that after a certain time, although we continue supplying heat to the steel, the temperature ceases to rise for a short time and then begins to rise again at a uniform rate. Evidently at this arrest point, termed a critical point, the heat which is being absorbed (decalescence), since it has not caused a rise in temperature, has caused a change to occur in the internal structure of the steel.

If the heating is continued, we find that a second arrest or critical point occurs, but the effect is not nearly as marked as the first point. At a higher temperature still, a third critical point occurs, similar in effect to the first.

If the steel is now allowed to cool at a uniform rate, we again have the three critical points corresponding to the three when the steel was heated, but they occur in each case at a slightly lower temperature than the corresponding point in the heating operation. At these points in the cooling operation, the metal gives out heat but the temperature remains steady. The evolution of heat on cooling through the critical range and which is visible in a darkened room is known as recalescence. The second arrest points which occur between upper and lower critical temperatures involve the loss and gain of magnetic properties and need not concern us here.

If the experiment is done with steels of varying carbon content it will be

found that the lower critical point is constant at about 720 °C for all steels, but the temperature of the upper critical point decreases with increasing carbon content, until at 0.85% carbon the two critical points occur at the same temperature. Figure 2.13 is part of the iron–carbon equilibrium or constitutional diagram which shows how the structure of any plain carbon steel changes with temperature and shows the limits of temperature and

Fig. 2.13

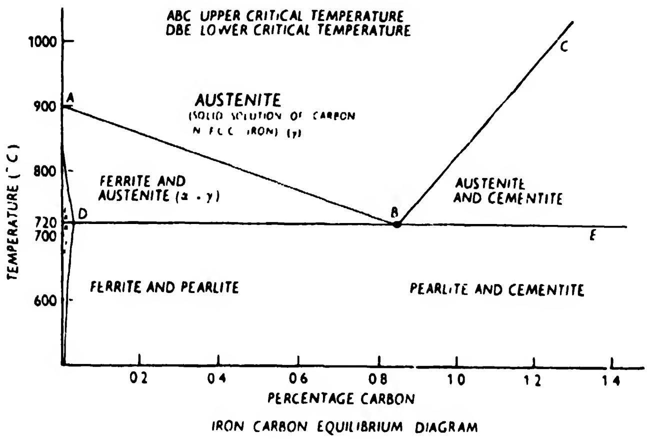
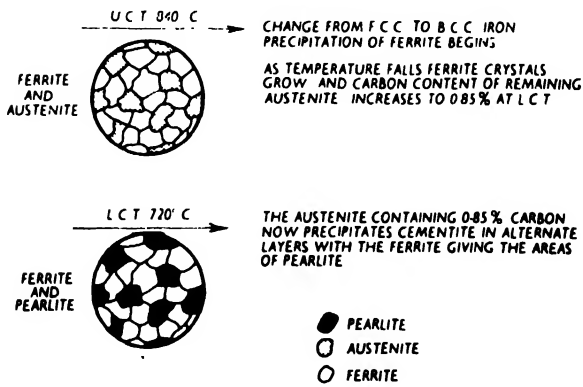


Fig. 2.14



composition in which the various constituents are stable (see Chapter 3 on equilibrium diagrams). We have seen that iron below 900 °C has a body-centred cubic structure (α iron), and in this state it can only have a trace of carbon in solution (up to 0.03% at 700 °C). When, however, the temperature rises above its upper critical point and the structure changes to face-centred cubic (γ iron), this type of iron can have up to 1.7% carbon in solution before it is saturated.* Thus when a steel is heated above its upper critical point the carbon, which was present in the combined form as cementite, dissolves in the iron to form a solid solution of iron and carbon, that is, dissolves completely in the iron although the iron is still in the solid state. This solid solution is called austenite (see Fig. 2.15*a*) and the carbon is diffused uniformly throughout the iron. Now let us lower the temperature of a 0.3% carbon steel slowly from above the upper critical point, about 850 °C. At the upper critical point the structure begins to change. Body-centred cubic crystals of ferrite are precipitated and the carbon content of the remaining austenite begins to increase. This continues as the temperature falls until at the lower critical point the austenite contains 0.85% carbon; it is saturated. The austenite now precipitates cementite (ferrite and carbon chemically combined) at the lower critical point, and it does this in alternate layers with the ferrite that is separating out, forming the areas of pearlite (Fig. 2.14). A 0.5% carbon steel will change in the same way, but begins the change at a lower temperature since the upper critical point is about 800 °C. In the case of a 0.85% carbon steel the transformation begins and ends at about 720 °C, since upper and lower critical points are at the same temperature, and the final structure will be all pearlite. A steel with more than 0.85% carbon will begin to precipitate carbon in the form of cementite at the upper critical point since carbon is in excess of 0.85%. At the lower critical point this transforms to pearlite so that the final structure is pearlite and cementite.

Heat treatment of steel

Hardening. In order to harden a carbon steel it must be heated to a temperature of 20–30 °C above its upper critical temperature and kept at this temperature long enough to ensure that the whole mass is at this temperature and the structure is austenitic. Maximum hardness can can now be obtained by quenching the steel in water or brine.

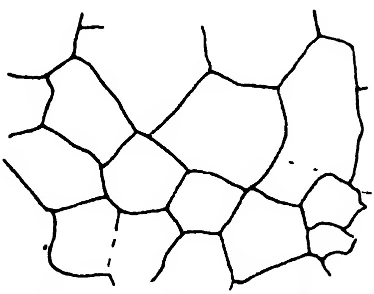
Examined under the microscope the structure appears as fine needle-like (acicular) crystals and is known as martensite (Fig. 2.15*b*); and the steel is hard and brittle. The rapid quench has prevented the normal change from

* At a temperature above that of the upper critical point the γ ferrite changes to a body centred cubic lattice and the iron is known as δ ferrite

austenite to ferrite and pearlite taking place. Quenching less severely produces bainite, a structure which when viewed under high magnification can be seen as an aggregate of ferrite and carbide particles like finely divided pearlite (Fig. 2.15*c*). Martensite and bainite are often found together in quenched steels.

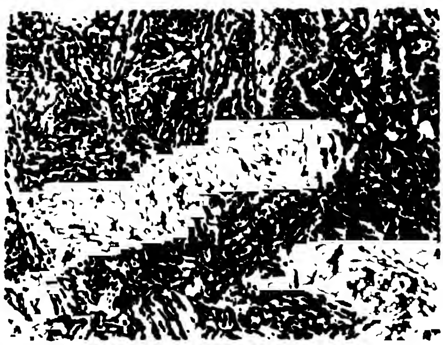
The rate of cooling is measured by the fall in temperature per second and can vary from a few to some hundreds of degrees depending upon the method used. The Critical Cooling Rate for a steel is the lowest rate at which a steel can be quenched to give an all-martensitic structure. At lower rates bainite and/or finely divided pearlite will form. If the steel has a large mass the outer layers will cool quickly when quenched, giving maximum hardness, while the core will cool much more slowly and will be softer (mass effect). Although simple shapes quench successfully, more complicated shapes may suffer distortion or cracking, or internal stresses may remain. In this case where a rapid quench would lead to complications, an alloy steel (e.g. one containing nickel) can be used instead of a plain carbon steel. The nickel lowers the critical cooling rate by slowing up the rate of transformation of austenite into its decomposition products so that a less drastic quench is required to produce martensite, reducing the mass effect and the risk of distortion, cracking and internal stresses.

Fig. 2.15
(*a*) Austenite in an 18% chromium 8% nickel steel sensitized and etched to show the grain boundaries ×500.
(*b*) Martensite. ×250.
(*c*) Bainite in a low chromium nickel and molybdenum steel transformed over the temperature range 570–430 °C ×500.



(*a*)

(*b*)



(*c*)

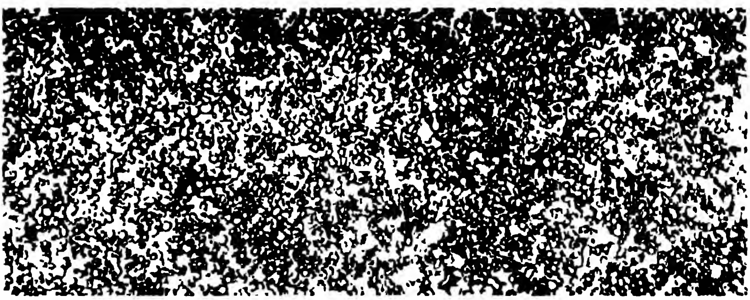
Air-hardened steels usually contain sufficient additions of nickel and chromium to reduce the critical cooling rate so that the steel is hardened by cooling in air, followed by tempering as required.

Quenching media include the following in decreasing order of quenching speed: caustic soda (sodium hydroxide), 5% solution; brine, 5–25% solution; cold water; hot water; mineral, animal, vegetable oils.

Tempering. The hardness and brittleness of a rapidly quenched steel together with the possibility that there may be internal stresses in the steel make the steel unsuitable for use unless the greatest possible hardness is required. The hardness and brittleness can be reduced and internal stresses relieved by tempering, in which process the hard and brittle martensitic structure is transformed to softer and more ductile structures but yet harder and tougher than ferrite and pearlite. To temper a steel it is re-heated to a definite temperature after hardening and then cooled.

(*a*) Heating to the range 200–250 °C relieves immediate lattice stress but the overall stress pattern persists to fairly high temperatures.

Fig. 2.16
(*a*) Spheroidised carbides in a 1 % carbon, 1 % chromium steel. Annealed × 700.
(*b*) Variation in particle size due to different tempering temperatures in a low alloy steel. × 250.



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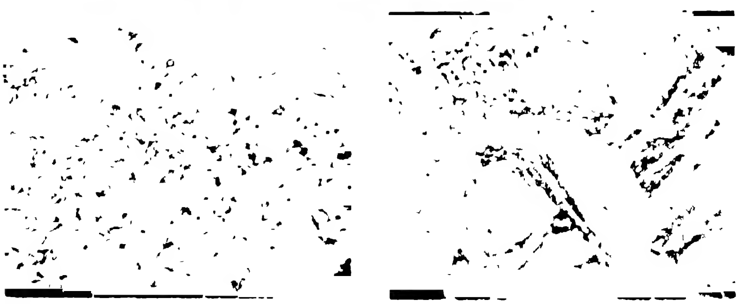


(*b*)

(*b*) Diffusion of carbon from martensite begins at about 150 °C and is practically complete at 350 °C. Heating to the range 150–350 °C forms a mixture of finely divided ferrite and cementite, not so hard but tougher than martensite.

(*c*) Coalescence of the carbides (cementite) starts at about 350 °C and is almost complete by about 650 °C, thus tempering in this range produces a structure similar to that in (*b*) but with larger particles and is softer and more ductile, the particle size depending upon the precise tempering temperature (Fig. 2.16*b*).

The structures obtained by tempering are stages in the austenite–pearlite transformation due to variations in the size and shape of the carbide particles and the way in which they are found in the ferrite matrix.

Interrupted quenching processes reduce internal stresses and distortion and reduce the possibility of quench cracking. If a steel is heated above its upper critical temperature and is then quenched in a bath of molten metal (lead or tin) or salt, kept at a fixed temperature, the quench is not so drastic and there is less temperature gradient between surface and core, reducing stress and distortion effects. If the steel is held at this temperature for varying periods of time and is then quenched out, time–temperature-transformation curves can be drawn indicating the various structures obtained by varying time and temperature.

A process termed martempering can be used to obtain a martensitic structure without the disadvantages of a drastic quench. The steel is quenched from the austenitic condition into a bath of molten metal kept at a temperature just above that at which martensite can form (260–370 °C) until it has a uniform temperature throughout and is then cooled in air, the structure being fine-grained martensite, and the thermal stresses are minimized. Austempering is an interrupted quenching process in which the steel is quenched from the austenitic condition into a bath of molten metal kept at a temperature below the critical range but above the temperature at which martensite can form. It is held at this temperature until complete transformation has occurred and then cooled to room temperature, the structure being pearlite and bainite.

A method often used to obtain a temper on a cutting tool consists of raising the part to bright red heat and then quenching the cutting end of the tool in water. The tool is then removed, any oxide that has formed is quickly polished off and the heat from the part which was not quenched travels by conduction to the quenched end, and the temper colours, formed by light interference on the different thicknesses of layers of surface oxide, begin to appear. The tool is then entirely quenched, when the required

colour appears. The colours vary from pale yellow (220 °C), through straw, yellow, purple brown, purple, blue to dark blue (300 °C).

Accurate control of tempering temperature can be obtained by using: furnaces with circulating atmospheres; oils for the lower temperature range; liquid salt (potassium nitrate, sodium nitrite, etc.); or liquid metal, e.g. lead.

Annealing. Annealing is the process by which the steel is softened, and internal strains are removed. The process consists of heating the metal to a certain temperature and then allowing it to cool very slowly out of contact with the air to prevent oxidation of the surface. After the first softening is obtained, if the annealing is prolonged, large crystals are formed. These, as is usual with all crystals, grow in size and decrease in number as the annealing continues. This is known as crystal growth or grain growth (Fig. 2.17).

As these grow in size, the resistance of the metal to shock and fatigue is greatly lowered; hence over-annealing has the bad effect of promoting grain growth, resulting in reduction in resistance to shock and fatigue.

The annealing temperature should be about 50 °C above the upper critical point and therefore varies with the carbon content of the steel. Low-carbon steel should therefore be heated to about 900 °C, while high-carbon steel should be heated to about 760 °C.

Use is made of the fact that iron (ferrite) recrystallizes at 500–550 °C in the treatment known as process annealing, which is used for mild steel articles which have been cold worked during manufacture. They can be packed in a box with cast iron filings over them, the lid luted on with clay, and then heated to 550–650 °C. Recrystallization of the ferrite takes place (there is little pearlite in the structure) and they are allowed to cool out very slowly in the box, after which considerable softening has taken place (Fig. 2.18).

High-carbon steels whose structure is mostly pearlite can be annealed by heating to 650–700 °C. At this temperature the cementite forms or balls up into rounded shapes, and the steel is softer and may be drawn and worked. At temperatures above this, pearlite is reformed and the steel becomes hard (Fig. 2.16*a*).

Normalizing. This process consists in raising the steel only slightly above the upper critical point, keeping it at this temperature for just sufficient time to heat it right through, and then allowing it to cool as rapidly as possible in air. This causes a refining of the structure, since recrystallization takes place, and a coarse structure becomes much finer, since the steel is not held

at the high temperature long enough for any grain (or crystal) growth to take place (see Fig. 2.17).

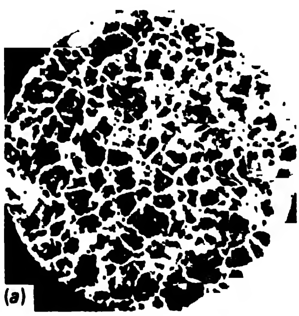
Overheated steel. If steel is exposed to too high a temperature or for too long a time to temperatures above the upper critical point it becomes overheated. This means that a very coarse structure occurs and, on cooling, this gives a similar coarse structure of ferrite and pearlite. This structure results in great reduction in fatigue resistance, impact strength, and a reduced yield point, and is therefore undesirable.

Steel which has been overheated is therefore extremely unsatisfactory. Correct heat treatment will restore the correct structure.

Burnt steel. If steel is heated to too high a temperature, this may result in a condition which cannot be remedied by heat treatment and the steel is said to be 'burnt'. This condition is due to the fact that the boundaries of the crystals become oxidized, due to absorption of oxygen at high temperature, and hence the steel is weakened (Fig. 2.19).

Case-hardening. Case-hardening (and also pack-hardening) is a method by which soft low-carbon steel is hardened on the surface by heating it in contact with carbonaceous material (material containing carbon). Parts to be case-hardened are packed in a box and covered with carbonaceous

Fig. 2.17 Grain growth due to normalizing at increasingly high temperatures × 100
(*a*) 0.4% carbon steel normalized at 850 °C
(*b*) 0.4% carbon steel normalized at 1000 °C
(*c*) 0.4% carbon steel normalized at 1200 °C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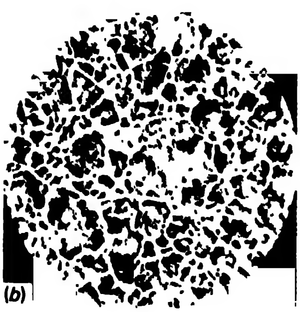
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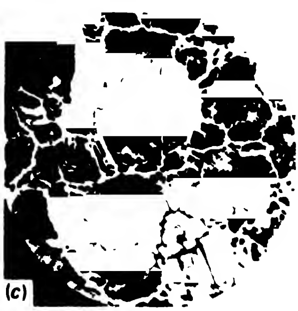

(*c*)

powder, such as charred leather, powdered bone, animal charcoal, or cyanide of potassium (KCN). The box is then placed in the furnace and heated above the critical temperature (that is, above 900 °C, depending on the carbon percentage in the steel). The steel begins to absorb carbon at red heat and continues to do so, the carbon diffusing through the surface. The box is then removed from the furnace and the parts on being taken out can either be directly water or oil quenched. Another favoured method is to allow them to cool out slowly, then heat up to about 800 °C, and quench in oil or water, depending on the hardness required in the case.

In the process known as gas carburizing, carbon is introduced into the surface of the part to be hardened by heating in a current of a gas with a high carbon content, such as hydrocarbons or hydrocarbons and carbon monoxide. This process is extensively used today and lends itself to automation with accurate control and uniformity of hardness.

Fig. 2.18. Heat treatment of steel

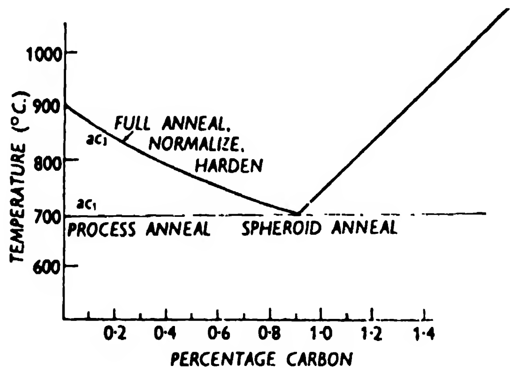


Fig. 2.19 Oxidation along crystal boundaries in mild steel which has been overheated and 'burnt'

The case-hardening furnace is almost always found nowadays as part of the equipment of large engineering shops. Parts such as gudgeon pins, shackle bolts and camshafts and, in fact, all types of components subject to hard wear are case-hardened.

The drawback to the process is that, owing to the quenching process, parts of complicated shape cannot be case-hardened owing to the risk of distortion.

The percentage of carbon in steels suited to case-hardening varies from 0.15 to 0.25%. Above this, the core tends to become hard. The carbon content of the case after hardening may be as high as 1.1%, but is normally about 0.9% to a depth of 0.1 mm.

Nitriding or nitrarding. This process consists of hardening the surface of 'nitralloy steels' (alloy steels containing aluminium and nickel) by heating the steel to approximately 500 °C in an atmosphere of nitrogen. The steel to be nitrarded is placed in the furnace and ammonia gas (NH_3) is passed through it. The ammonia gas splits up, or 'cracks', and the nitrogen is absorbed by the steel, while the hydrogen combines with the oxygen and steam is formed, passing out of the furnace. The parts are left in the furnace for a period depending on the depth of hardening required, because this process produces a hardening effect which decreases gradually from the surface to the core and is not a 'case' or surface hardening. When removed from the furnace, the parts are simply allowed to cool. The nitralloy steel is annealed before being placed in the furnace and the parts can be finished to the finest limits, since the heat of the furnace is so low (500 °C) that distortion is reduced to a minimum, and there is no quenching. Nitralloy steel, after the nitrarding process, is intensely hard, and it does not suffer from the liability of the surface to 'flake' as does very hard case-hardened steel.

It is used extensively today in the automobile and aircraft industries for parts such as crankshafts, pump spindles, etc.

The effect of welding on the structure of steel

A typical analysis of all-weld metal-deposit mild steel is: carbon 0.06–0.08%, manganese 0.43–0.6%, silicon 0.12–0.4%, sulphur 0.02% max., phosphorus 0.03% max., remainder iron. During the welding process, the molten metal is at a temperature of from 2500 to 3000 °C and the weld may be considered as a region of cast steel. Since regions near the weld may be comparatively cool, giving a steep thermal gradient from weld

to parent plate, it will be possible to find crystal structures of all types in the vicinity, and great changes may take place as the rate of cooling is altered.

A typical cross section from the molten pool to the cold section of the parent plate might reveal the following regions (Fig. 2.20).

(*a*) The molten pool with parent plate and weld metal mixed at temperatures above the melting point, 1500 °C.

(*b*) A region of BCC delta iron and austenite (FCC gamma iron) mixed.

(*c*) A region of austenite above the upper critical temperature, 900–1400 °C.

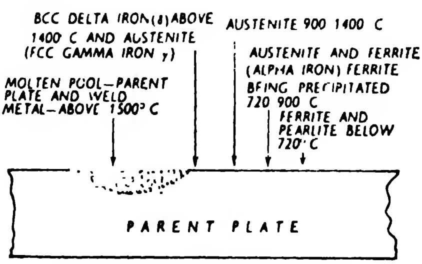
(*d*) A region of austenite and ferrite (BCC alpha iron), where ferrite is being precipitated (between upper and lower critical temperatures).

(*e*) The parent plate of ferrite and pearlite.

There is a high possibility, in addition, that oxygen or even nitrogen may be absorbed into the weld itself. We have seen that when oxidation occurs on the crystal boundaries, the impact strength and fatigue resistance of the metal are greatly reduced, and hence a weld which has absorbed oxygen will show these symptoms. The formation of iron nitride (Fe_4N) also makes the weld brittle. The nitride is usually present in the form of fine needle-shaped crystals visible under the high-powered microscope. The weld must be safeguarded from these defects as much as possible.

Evidently, also, the composition of the filler rod or electrode compared with that of the parent metal will be of great importance, since this will naturally alter the properties of the steel at or near the weld. If the mass of the parent metal is small and cooling is very quick, the weld may be tough and strong but brittle due to the presence of martensite and this will particularly be the case if the carbon content is high. If, however, cooling is

Fig 2.20



TYPES OF IRON PRESENT WHEN WELDING MILD STEEL PLATE

slow, structures of varying forms of ferrite and pearlite are found, giving a lower strength and decreased hardness, but at the same time a very much increased ductility and impact strength. Evidently, therefore, the welding of a given joint requires consideration as to what properties are required in the finished weld (tenacity, ductility, impact strength, resistance to wear and abrasion, etc.). When this is settled the method of welding and the rate of cooling can be considered, together with the choice of suitable welding rods.

These considerations are of particular importance in the case of the welding of alloy steels, since great care is necessary in the choice of suitable welding rods, which will give the weld the correct properties required. In many cases, heat treatment is advisable after the welding operation, to remove internal stresses and to modify the crystal structure, and this treatment must be given to steels such as high-tensile and chrome steels. The study of welding of these steels is, however, still proceeding (Chapter 8).

During the welding process, the part of the weld immediately under the flame or arc is in the molten condition, the section that has just been welded is cooling down from this condition, while the section to be welded is comparatively cold. This, therefore, is virtually a small steel-casting operation, the melting and casting process taking place in a very short time and the weld metal after deposition being 'as cast' steel.

As a result we expect to find most of the various structures (martensite, bainite) that we have considered, and the point of greatest interest to the welder is, what structures will remain on cooling. Evidently the structure that remains will determine the final strength, hardness, ductility and resistance to impact of the weld. Since these structures will be greatly affected by the absorption of any elements that may be present, it will be well to consider these first.

Oxygen

Oxygen may be absorbed into the weld, forming iron oxide (Fe_3O_4) and other oxides such as that of silicon. This iron oxide may also be absorbed into the weld from the steel of the welding rod or electrode. If iron oxide is formed it may react with the carbon in the steel to form carbon monoxide, resulting in blowholes. If this iron oxide is present in any quantity (as in the case when using bare wire electrodes in arc welding, or excess of oxygen in the oxy-acetylene process), oxidation of the weld will occur and this produces a great increase in the grain size, which is easily observed on the microphotograph. Even normalizing will not then produce

a fine grain. This oxygen absorption, therefore, has a bad effect on the weld, reducing its tensile strength and ductility and decreasing its resistance to corrosion. Covered arc welding electrodes may contain deoxidizing material to prevent the formation of iron oxide, or sufficient silica to act on the iron oxide to remove it and form iron silicate (slag).

Nitrogen

The percentage of nitrogen in weld metal can vary considerably, and the results of experiments performed have led to the following conclusions:

(*a*) There is very low absorption by the oxy-acetylene process (maximum 0.02%).

(*b*) There is much greater absorption in arc welding (0.15 to 0.20%) which is influenced by (1) the current conditions that may cause the nitrogen content to vary from 0.14 to 0.2%, (2) the nature of the atmosphere. By the use of electrodes covered with hydrogen-releasing coatings, e.g. sawdust, the nitrogen content may be brought down to 0.02%.

(*c*) As regards the thickness of the coatings, use of a very thick covering may reduce the nitrogen from 0.15 to 0.03%.

Nitrogen is found in the weld metal trapped in blowholes (although nitrogen itself does not form the blowholes) and as crystals of iron nitride (Fe_4N), known as nitride needles. Nitrogen, however, may be in solution in the iron, and to cause the iron nitride needles to appear the weld has to be heated up to about 800–900 °C. The nitrogen tends to increase the tensile strength but *decreases* the ductility of the metal. Low-nitrogen steels are now supplied when required for deep pressing since they are less prone to cracking.

Hydrogen

Hydrogen is absorbed into mild steel weld metal during arc welding with covered electrodes. The hydrogen is present in the composition of many flux coatings and in their moisture content. It begins to diffuse out of the weld metal immediately after the welding process, and continues to do so over a long period. The presence of this hydrogen reduces the tensile strength of the weld. (An experiment to illustrate this is given in Chapter 8.)

Carbon

If we attempt to introduce carbon into the weld metal from the filler rod, the carbon either oxidizes into carbon monoxide during the

melting operation or reacts with the weld metal and produces a porous deposit. Arc welded metal cools more quickly than oxy-acetylene welded metal and hence the former may be expected to give a less ductile weld, but the quantity of carbon introduced in arc welding (pick-up) is too small to produce brittle welds in this way.

The effect on the weld metal of the carbon contained in the parent metal is, however, important, especially when welding medium or high carbon steels. In this case, the carbon may diffuse from the parent metal, due to its relatively high carbon content, into the weld metal and form, near the line of fusion of weld and parent metal, bands of high carbon content sufficient to produce hardness and brittleness if cooled rapidly.

Structural changes

The question of change of structure during welding depends amongst other things on:

(1) The process used.
(2) The type and composition of the filler rod and, if arc welding is employed, the composition of the covering of the electrode.
(3) The conditions under which the weld is made, i.e. the amount of oxygen and nitrogen present.
(4) The composition of the parent metal.

The change of structure of the metal is also of great importance, as previously mentioned. This will depend largely upon the amount of carbon and other alloying elements present and upon the rate at which the weld cools.

In arc welding the first run of weld metal flowing onto the cold plate is virtually chill cast. The metal on the top of the weld area freezes quickly as the heat is removed from it and small chill crystals are formed. Below, these crystals grow away from the sides towards the hotter regions of the weld metal and thus growth is faster than the tendency to form new dendrites so that columnar crystals are formed.

Because of the high temperature of the molten metal in arc welding these crystals have enough time to grow. On each side of the weld is a heat-affected zone in which the temperature has been raised above the recrystallization temperature and in which, therefore, grain growth has occurred. Beyond this zone the plate structure is unaffected (Figs. 2.21, 2.24).

When a second run is placed over the first there will be:

(1) A refined area in the first run where recrystallization temperature is exceeded and the columnar crystals of the first run are reformed as small equi-axed crystals.

(2) A region between this and the parent plate where grain growth has taken place because the temperature has been well above re-crystallization temperature.

(3) The second run will form columnar crystals on its below surface layers because of the quick cooling when in contact with the atmosphere (Figs. 2.22, 2.25).

In gas welding the heat-affected zone will be wider than in arc welding because, although the flame temperature is below that of the arc, the arc is more localized and the temperature is raised more quickly. When the flame is applied to the plate its temperature is raised so that chill casting does not occur. Grain growth, however, will be more pronounced because the heat is applied for a longer period than in arc welding (Fig. 2.23*a*, *b*).

A consideration of this subject makes very evident the reason why austenitic alloy steels present such a problem in welding. These steels owe their properties to their austenitic condition, and immediately they are subjected to the heat of the welding process, they have their structure greatly modified. It is nearly always imperative that after welding steels of

Fig. 2.21

MACROSTRUCTURE OF SINGLE ARC RUN ON MILD STEEL PLATE (COLD WORKED)

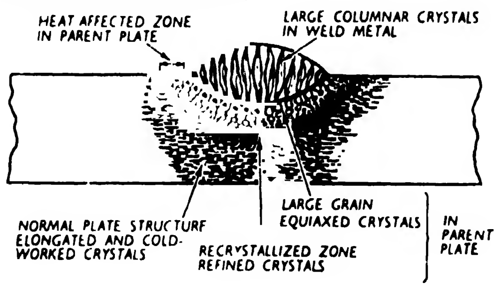
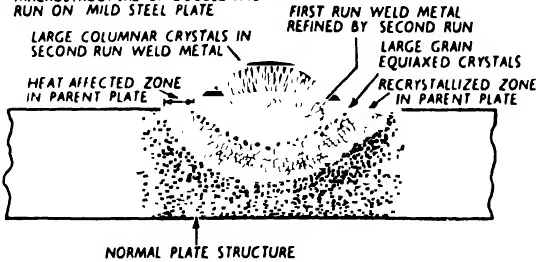


Fig. 2.22

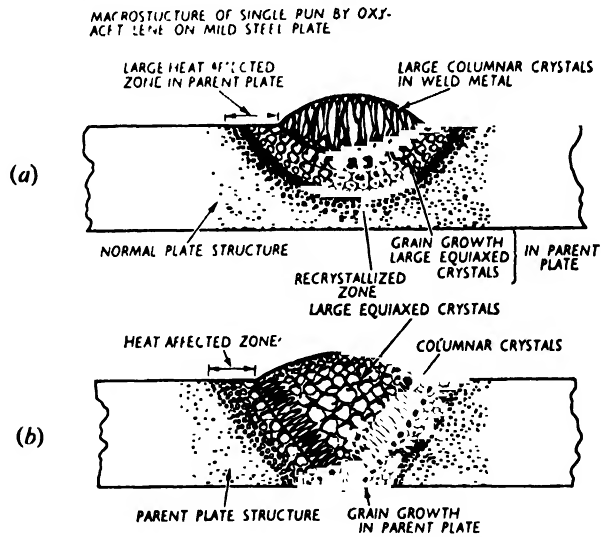
MACROSTRUCTURE OF DOUBLE ARC RUN ON MILD STEEL PLATE



this class, they should be heat treated in order to correct as far as possible this change of structure. In addition, owing to the number of alloying elements contained in these steels, it becomes very difficult to obtain a weld whose properties do not differ in a marked degree from those of the parent metal. Hence the welding of alloy steels must be considered for each particular steel and with reference to the particular requirements and service conditions. In addition, great care must be taken in selecting a suitable electrode or filler rod.

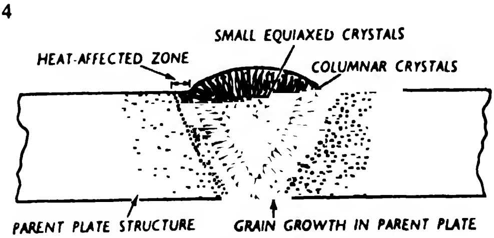
The microscope can be used extensively to observe the effect of welding on the structure. When once the observer is trained to recognize the various structures and symptoms, the microscope provides accurate information about the state of the weld. The microscope can indicate the following

Fig 2 23



OXY-ACETYLENE WELD IN MILD STEEL PLATE

Fig 2 24



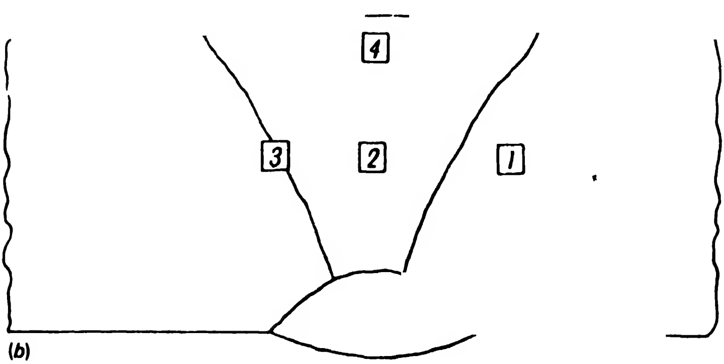
ELECTRIC ARC WELD IN MILD STEEL PLATE

points, which can hardly be found by any other method and, as previously mentioned, can also indicate fine hair cracks unperceived in X-ray photographs, together with any slag inclusions and blowholes of microscopic proportions. Faults in structure indicated by the microscope using various magnifications are:

(1) True depth of penetration of the weld as indicated by the crystal structure.
(2) The actual extent of the fusion of weld and parent metal (Fig. 2.24).
(3) The actual structure of the weld metal and its conditions (Figs. 2.24, 2.25, 2.26, 2.27).
(4) The area over which the distribution due to the heating effect of the welding operation has occurred.
(5) The amount of nitrogen and oxygen absorption, as seen by the presence of iron oxide and iron nitride crystals.

Fig. 2.25. Section of a flat butt weld in rolled steel plate (× 3). Macrographs of the regions labelled 1, 2, 3 and 4 are shown in Figs. 2.26 and 2.27.

(a)



(b)

Dilution

When two metals are fusion welded together by metal arc, TIG, MIG or submerged arc processes, the final composition consists of an admixture of parent plate and welding wire. The parent plate has melted in with the filler and has diluted it and this dilution may be expressed as a percentage thus:

$$\text{percentage dilution} = \frac{\text{weight of parent metal in weld}}{\text{total weight of weld}} \times 100.$$

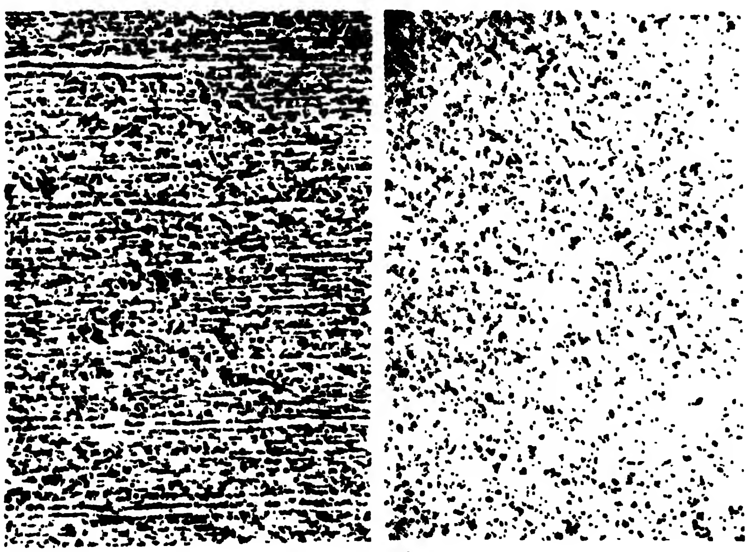
If there are 15 parts by weight of parent plate in 75 parts by weight of weld metal then the dilution is $15/75 \times 100 = 20\%$.

Average values of dilution for various processes are:

Metal arc	25-40%
Submerged arc	25–40%
MIG (spray transfer)	25–50%
MIG (dip transfer)	15–30%
TIG	25–50%

and it can be seen that minimum dilution is obtained using MIG (dip transfer). Many factors affect dilution. Evidently with a single-run weld

Fig. 2.26
(1) Rolled steel plate. × 75.
(2) Weld metal showing refined structure. × 75.

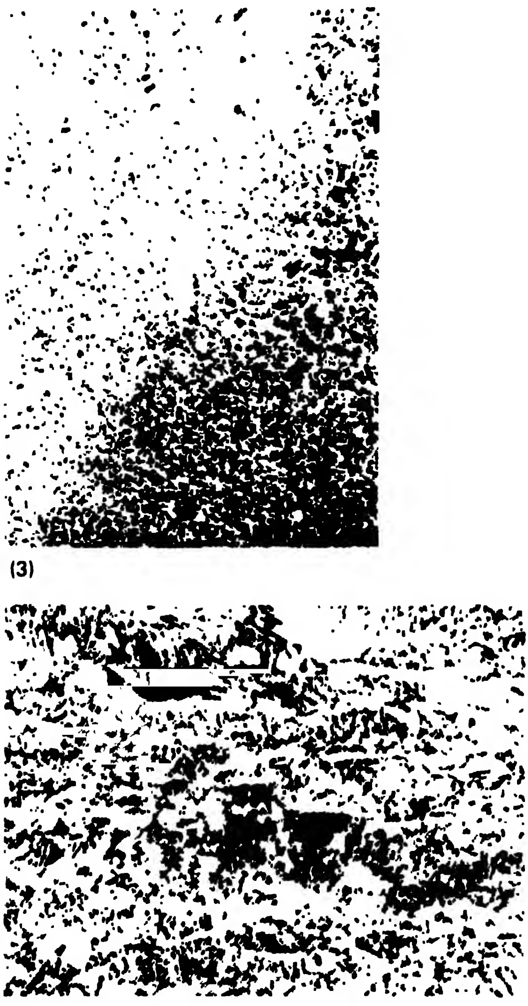


(1) (2)

there will be greater dilution than with multi-runs and there is always considerable dilution in any root run. The greater the amount of weaving the greater the dilution.

When dissimilar metals are to be welded together the final weld will suffer dilution from each parent plate and for a successful weld it must do so without major defects, including liability of cracking. In addition the physical and mechanical properties and resistance to corrosion must be as

Fig 2.27
(3) Junction of weld metal and plate. × 75
(4) Top layer × 75.



(3)

(4)

near as possible to those of the parent plate. As all these criteria are not generally obtainable a welding wire must be chosen which gives the optimum properties for a given situation.

Example

A plate of 9% Ni steel is welded with a welding wire of composition 80% Ni–20% Cr. What will be the approximate composition of the final weld if there is 40% dilution?

With 40% dilution the plate will contribute 40% and the welding wire 60%.

	Nickel	Iron	Chromium
9% nickel plate	$\frac{40}{100} \times 9 = 3.6$	$\frac{40}{100} \times 91 = 36.4$	
80% Ni-20% Cr welding wire	$\frac{60}{100} \times 80 = 48$		$\frac{60}{100} \times 20 = 12$
	51.6	36.4	12

Therefore the approximate composition of weld metal is:

51.5% Ni, 36.5% Fe, 12% Cr.

A plate of an alloy of composition 70% Ni–30% Cu is to be welded to a plate of alloy steel of composition 18% Cr 12% Ni–70% Fe using a wire of composition 75% Ni-15% Cr–8% Fe. Assuming 30% dilution, what will be the approximate composition of the final weld?

With 30% dilution each plate will contribute 15% and the welding wire 70%.

	Nickel	Chromium	Copper	Iron
70% Ni 30% Cu alloy plate	$\frac{15}{100} \times 70 = 10.5$		$\frac{15}{100} \times 30 = 4.5$	
Alloy steel plate	$\frac{15}{100} \times 12 = 1.8$	$\frac{15}{100} \times 18 = 2.7$		$\frac{15}{100} \times 70 = 10.5$
Welding wire	$\frac{70}{100} \times 75 = 52.5$	$\frac{70}{100} \times 15 = 10.5$	4.5	$\frac{70}{100} \times 8 = 5.6$
	64.8	13.2		16.1

Therefore the approximate composition of weld metal is:

65% Ni, 13% Cr, 4.5% Cu, 16% Fe.

Pick-up. This is the term applied to the absorption or transfer of elements from parent plate or non-consumable electrode into the weld metal and is closely associated with dilution. When overlaying plain low-carbon steels with nickel-base alloys there is a tendency for the weld metal to pick up iron from the parent plate, resulting in a lowering of corrosion resistance of the overlay. The pick-up must be kept as low as possible. When welding cast

iron with the metal arc processes carbon pick-up can lead to the undesirable excessive precipitation of carbides, which are hard and brittle. Tungsten pick-up can occur when welding with the gas-shielded tungsten electrode (TIG) process when excessive currents are used, resulting in the pick-up of tungsten particles from the electrode into the weld metal (Chapter 10).

Cracking in steel

A crack is a fissure produced in a metal by tearing action. Hot or solidification cracking is caused in the weld metal itself by tearing of the grain boundaries before complete solidification has taken place and while the metal is still in the plastic state. The crack may be continuous or discontinuous and often extends from the weld root and may not extend to the face of the weld. Cold cracking occurs in both weld metal and adjacent parent plate (HAZ) and may be due to excessive restraint on the joint, insufficient cross-sectional area of the weld, presence of hydrogen in the weld metal or embrittlement in the HAZ of low alloy steels.

Factors which may promote hot cracking

Current density: a high density tends to promote cracking.
The distribution of heat and hence stress in the weld itself.
Joint restraint and high thermal severity.
Crack sensitivity of the electrode.
Dilution of the weld metal.
Impurities such as sulphur, and high carbon or nickel content.
Pre-heating, which increases the liability to cracking.
Weld procedure. High welding speeds and long arc increase sensitivity and crater cracking indicates a crack sensitivity.

Factors which may promote cold cracking

Joint restraint and high thermal severity.
Weld of insufficient sectional area.
Hydrogen in the weld metal.
Presence of impurities.
Embrittlement of the HAZ (low-alloy steels).
High welding speeds and low current density.

The effect of deformation on the properties of metals

Cold working

When ductile metal is subjected to a stress which exceeds the elastic limit, it deforms plastically by an internal shearing process known as *slip*. *Plastic* deformation is permanent so that when the applied stress is removed the metal remains deformed and does not return to its original size and shape as is the case with *elastic* deformation.

Plastic deformation occurs in all shaping processes such as rolling, drawing and pressing, and may occur locally in welded metals owing to the stresses set up during heating and cooling. When plastic deformation is produced by cold working it has several important effects on the structure and properties of metal:

(1) The metal grains are progressively elongated in the direction of deformation.

(2) With heavy reduction by cold work the structure becomes very distorted, broken up, and fibrous in character.

(3) If there is a second constituent present, as in many alloys, this becomes drawn out in threads or strings of particles in the direction of working, thus increasing the fibrous character of the material.

(4) The deformation of the structure is accompanied by progressive hardening, strengthening and loss of ductility and by an increased resistance to deformation. Cold worked metals and alloys are therefore harder, stronger and less ductile than the same materials in the undeformed state. The properties of cold worked materials may also differ in different directions owing to the fibrous structure produced

(5) If the deformation process does not act uniformly on all parts of the metal being rolled or drawn, then internal stresses may be set up. These stresses may add to a subsequent working stress to which the metal is subjected, and they also render many metals and alloys subject to a severe form of intercrystalline corrosion, known as stress-corrosion; for example, the well-known season cracking of cold worked brass.

(6) If the deformation process is carried to its limit, the metal loses all of its ductility and breaks in a brittle manner. Brittle fracture of a similar kind can be produced in metals without preliminary deformation if they are subjected to certain complex stress systems which prevent deformation by slipping (three tensile stresses acting perpendicularly to each other). Such conditions can occur

in practice in the vicinity of a notch and are sometimes set up in the regions affected by welding.

The effect of heat on cold worked metals : annealing and recrystallization

On heating a cold worked metal, the first important effect produced is the relief of internal stress. This occurs without any visible change in the distorted structure. The temperature at which stress relief occurs varies from 100 °C up to 500 °C according to the particular metal concerned. In general, the higher the melting point, the higher is the temperature for this effect.

On further heating the cold worked metal, no other changes occur until a critical temperature known as the 'recrystallization temperature' is reached. At the recrystallization temperature, the distorted metal structure is able to re-arrange itself into the normal unstrained arrangement by recrystallizing to form small equi-axed grains. The mechanical properties return again to values similar to those which the metal possessed before the cold working operation, i.e. hardness and strength fall, and ductility increases. However, if the extent of the distortion was very severe (suppose for example there had been a 60% or more reduction by rolling) the recrystallized metal may exhibit different properties in different directions.

If the metal is heated to a higher temperature than the minimum required for recrystallization to occur, the new grains grow progressively larger and the strength and working properties deteriorate.

The resoftening which accompanies recrystallization is made use of during commercial cold working processes to prevent the metal becoming too brittle, as, for example, after a certain percentage of reduction by cold rolling, the metal is annealed to soften it, after which further reduction by cold working may be done.

The control of both working and annealing operations is important because it affects the grain size, which, in turn, controls the properties of the softened material. It is generally advantageous to secure a fine grain size. The main factors determining the grain size are:

(1) The prior amount of cold work – the recrystallized grain size decreases as the amount of prior cold work increases.

(2) The temperature and time of the annealing process. The lowest annealing temperature which will effect recrystallization in the required time produces the finest grain size.

(3) Composition. Certain alloying elements and impurities restrict grain growth.

The temperature at which a cold worked metal or alloy will recrystallize depends on:

(1) Its melting point. The higher the melting point the higher the recrystallization temperature.

(2) Its composition and constitution. Impurities or alloying elements present in solid solution raise the recrystallization temperature. Those present as second constituents have little effect (although these are the type which tend to restrict grain growth once the metal or alloy has recrystallized).

(3) The amount of cold work. As the extent of prior cold work increases, so the recrystallization temperature is lowered.

(4) The annealing time. The shorter the time of annealing the higher the temperature at which recrystallization will occur.

These factors must all be taken into account in determining practical annealing temperatures.

Hot working

Metal and alloys which are not very ductile at normal temperatures, and those which harden very rapidly when cold worked, are generally fabricated by hot working processes, namely forging, rolling, extrusion, etc. Hot working is the general term applied to deformation at temperatures above the recrystallization temperature. Under these conditions the hardening which normally accompanies the deformation is continually offset by recrystallization and softening. Thus a hot worked material retains an unstrained equi-axed grain structure, but the size of the grains and the properties of the structure depend largely on the temperature at which working is discontinued. If this is just above the recrystallization temperature, the grains will be unworked, fine and uniform, and the properties will be equivalent to those obtained by cold working followed by annealing at the recrystallization temperature.

If working is discontinued well above the recrystallization temperature, the grains will grow and develop inferior properties, while a duplex alloy may develop coarse plate structures similar to those present in the cast state and have low shock-strength.

On the other hand, if working is continued until the metal has cooled below its recrystallization temperature, the grains will be fine but will be distorted by cold working, and the metal will therefore be somewhat harder and stronger but less ductile than when the working is discontinued at or above the recrystallization temperature.

Insoluble constituents in an alloy become elongated in the direction of work as in cold working and produce similar directional properties.

Hot working is used extensively for the initial 'breaking down' of large ingots or slabs, even of metals which can be cold worked. This is because of the lower power required for a given degree of reduction by hot work. Hot work also welds up clean internal cavities but it tends to give inferior surface properties since some oxide scale is often rolled into the surface. Further, it does not permit such close control of finishing gauges, and cannot be used effectively for finishing sheet or wire products.

Impurities which form low melting point constituents can ruin the hot working properties of metals and alloys, for example excess sulphur in steel.

Cold working as a major fabrication process is restricted to very ductile materials such as pure and commercial grades of copper, aluminium, tin and lead, and to solid solution alloys, such as manganese–aluminium alloys; brasses, containing up to 35% zinc; bronzes containing up to 8% tin; copper–nickel alloys; aluminium bronzes, containing up to 8% aluminium; nickel silvers (copper nickel -zinc alloys) and tin -base alloys such as pewter. It is also used in the finishing working stages of many other metals and alloys to give dimensional control, good surface quality and the required degree of work hardening.

Iron, steels, high zinc or high aluminium copper alloys, aluminium alloys such as those with copper, magnesium and zinc, pure zinc and pure magnesium, and the alloys of these metals are all generally fabricated by hot working, though cold working may be used in the late stages, especially for the production of wire or sheet products.

Iron and steel

Pure iron is very ductile and can be both hot and cold worked.

The carbon content of steel makes it less ductile than iron. Dead mild steel of up to 0.15% carbon is very suitable for cold working and can be flanged and used for solid drawn tubes. Although it is slightly hardened by cold work the modulus of elasticity is unaffected. If steel is hot worked at a temperature well above the recrystallization temperature, grain growth takes place and the impact strength and ductility are reduced, hence it should be worked at a temperature just above the recrystallization point, which is 900–1200°C for mild steel and 750–900°C for high-carbon steel. Thus, in general, hot working increases the tensile and impact strength compared with steel in the cast condition, and as the carbon content increases, the steel become less ductile and it must be manipulated by hot working.

Copper

Copper is very suitable for cold working as its crystals are ductile and can suffer considerable distortion without fracture, becoming harder, however, as the amount of cold work increases. Since welding is performed above the annealing temperature it removes the effect of cold work.

Copper is very suitable for hot working and can be hot rolled, extruded and forged.

Brasses

Brasses of the 85/15 and 70/30 composition are very ductile. Brass can be heavily cold worked without suffering fracture. This cold work modifies the grain structure, increases its strength and hardens and gives it varying degrees of temper.

Since these brasses are so easily cold worked there is little advantage to be gained by hot work which however, is quite suitable.

For brass of the 60/40 type ($\alpha+\beta$ structures) see pp. 123–5.

The β structure, which is zinc rich, is harder than the α structure and will stand little cold work without fracture. If the temperature is raised, however, to about 600 °C it becomes more easily worked.

Brasses of this composition therefore should be hot worked above 600–700 °C giving a fine grain and fibrous structure. Below 600 °C for this structure can be considered cold work.

Copper–nickel alloys

80/20 copper-nickel alloy is suitable for hot and cold work but is particularly suitable for the latter due to its extreme ductility.

Nickel–chrome alloys are generally hot worked.

Bronzes. Gunmetal (Cu 88%, Sn 10%, Zn 2%) must be hot worked above 600 °C and not cold worked. Phosphor bronze with up to 6–7% tin can be cold worked.

Aluminium bronze is similar to brass in being of two types:

(1) α structure containing 5–7% Al, 93% Cu.

(2) $\alpha + \beta$ structure containing 10% Al, 90% Cu.

(1) The α structure, which is the solid solution of aluminium in copper, is ductile and this type is easily worked hot or cold.

(2) The $\alpha + \beta$ structure is rendered more brittle by the presence of the β constituent, which becomes very hard and brittle at 600 °C due to the formation of another constituent which, in small quantities, increases the tensile strength; hence this alloy must be hot worked.

Aluminium. Pure aluminium can be worked hot or cold but weldable alloys of the work hardening type such as Al-Si, Al-Mn and Al-Mn-Mg, are hardened by cold work which gives them the required degree of temper and they soften at 350 °C. Duralumin is hot short above 470 °C and too brittle to work below 300 °C so it should be worked in the range 400-470 °C. Y alloy can be hot worked.

Non-ferrous metals

Copper

Copper is found in the ore copper pyrites ($CuFeS_2$) and is first smelted in a blast or reverberatory furnace, and is then in the 'blister' or 'Bessemer' stage. In this form it is unsuitable for commercial use, as it contains impurities such as sulphur and oxygen. Further refining may be carried on by the furnace method, in which oxidation of the sulphur and other impurities occurs, or by an electrical method (called electrolytic deposition), resulting in a great reduction of the impurities.

In the refining and melting processes, oxidation of the copper occurs and the excess oxygen is removed by reducing conditions in the furnace. This is done by thrusting green wooden poles or tree trunks under the surface of the molten copper, which is covered with charcoal or coke to exclude the oxygen of the air. The 'poling', as it is called, is continued until the oxygen content of the metal is reduced to the limits suitable for the work for which the copper is required.

The oxygen content of the copper is known as the 'pitch' and poling is ended when the 'tough pitch' condition is reached.

Oxygen in copper. In this condition the oxygen content varies from 0.025 to 0.08%. The oxygen exists in the cast copper as minute particles of cuprous oxide (Cu_2O) (Fig. 2.28*a*).

The amount of oxygen in the copper is most important from the point of view of welding, since the welding of copper is rendered extremely difficult by the presence of this copper oxide. When molten, copper oxide forms a eutectic with the copper and this collects along the grain boundaries, reducing the ductility and increasing the tendency to crack. Any hydrogen present, as occurs when there are reducing conditions in the flame, reduces the copper oxide to copper and water is also formed. This is present as steam, which causes porosity and increases the liability of cracking. For welding purposes, therefore, it is much preferable to use copper almost free from oxygen, and to make this, deoxidizers such as phosphorus, silicon, lithium, magnesium, etc., are added to the molten metal, and they combine

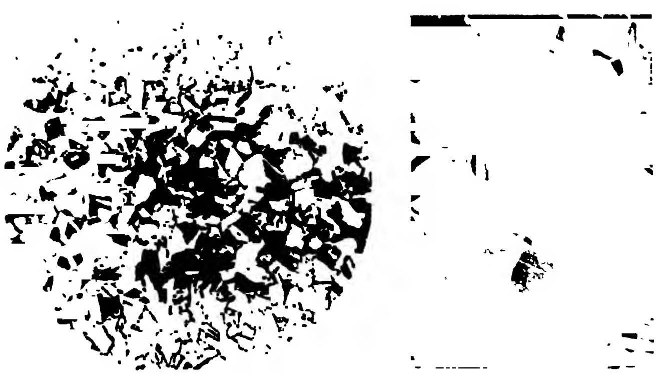
with oxygen to form slag and thus *deoxidize* the copper (Fig. 2.28*b*). The welding of 'tough pitch' copper depends so much on the skill of the welder that it is always advisable to use 'deoxidized copper' for welding, and thus eliminate any uncertainty.

Arsenic in copper. When arsenic up to 0.5% is added to copper, the strength and toughness is increased. In addition to this, it increases its resistance to fatigue and raises by about 100 °C the temperature at which softening first occurs and enables it to maintain its strength at higher temperatures. Arsenic is undesirable in copper intended specifically for welding purposes, since it makes welding more difficult. Arsenical copper can be welded by the same method as for ordinary copper, and if care is taken the welds are quite satisfactory. As with ordinary copper, it may be obtained in the deoxidized or the tough pitch form, the former being the more suitable for welding.

Properties of copper. Copper is a red-coloured metal having a melting point of 1083 °C and a density of 8900 kg/m³. The mechanical properties of copper depend greatly on its condition, that is, whether it is in the 'as cast' condition or whether it has been hot or cold worked, hammered, rolled, pressed, or forged.

The tensile strength 'as cast' is about 160 N/mm². Hot rolling and forging, followed by annealing, modifies its structure and increases its strength to about 220 N/mm². Cold working by hammering, rolling, drawing and pressing hardens copper and raises its tensile strength, but it becomes less ductile.

Fig. 2.28
(*a*) Cuprous oxide in copper × 100
(*b*) Deoxidized copper × 75



(*a*) (*b*)

Very heavy cold worked copper may have a tensile strength equal to that of mild steel, but it has very little ductility in this state.

The temper of copper. Copper is tempered by first getting it into a soft or annealed condition, and then the temper required is obtained by cold working it (hammering, rolling, etc.). Thus it is the reverse process from the tempering of steel. Soft-temper copper is that in the annealed condition. It has a Brinell hardness of about 50. After a small amount of cold working, it becomes 'half hard' temper, and further cold working makes it hard temper having a Brinell figure of about 100. Intermediate hardness can of course be obtained by varying the amount of cold working.

Annealing. Copper becomes hard and its structure is deformed when cold worked, and annealing is therefore necessary to soften it again. To anneal the metal, it is usual to heat it up to about 500 C, that is, dull red heat, and either quench it in water or let it cool out slowly, since the rate of cooling does not affect the properties of the pure metal. Quenching, however, removes dirt and scale and cleans the surface. The surface of the copper can be further cleaned or 'pickled' by immersing it in a bath of dilute sulphuric acid containing 1 part of acid to 70 parts of water. If nitric acid is added, it accelerates the cleaning process. If copper has a surface polish, heating to the annealing temperature will cause the surface to scale, which is undesirable; hence annealing is usually carried out in a non-oxidizing atmosphere in this case.

Crystal or grain size. Under the microscope, cold worked copper shows that the grains or crystals of the metal have suffered distortion. During the annealing process, as with steel, recrystallization occurs and new crystals are formed. As before, if the annealing temperature is raised too high or the annealing prolonged too long, the grains tend to grow. With copper, however, unlike steel, the rate of growth is slow, and this makes the annealing operation of copper subject to a great deal of latitude in time and temperature. This explains why it is immaterial whether the metal cools out quickly or slowly after annealing.

The main grades in which copper is available are: (1) oxygen-bearing (tough pitch) high conductivity; (2) oxygen-free high conductivity; (3) phosphorus deoxidized.

Alloys of copper

The alloys of copper most frequently encountered in welding are: copper–zinc (brasses and nickel silvers); copper tin (phosphor bronzes and gunmetal); copper silicon (silicon bronzes); copper–aluminium (alum-

inium bronzes); copper–nickel (cupro-nickels); and heat-treatable alloys such as copper–chromium and copper–beryllium. These are also discussed in the section on the welding of copper by the TIG process.

Filler metals for gas-shielded arc welding of copper (conforming to BS 2901)

BS2901 designation	Nominal composition (%)
C7	0.15 0.35 Mn; 0.20–0.35 Si; Rem. Cu
C8	0.1–0.3 Al; 0.1–0.3 Ti; Rem. Cu
C9	0.75 1.25 Mn; 2.75–3.25 Si; Rem. Cu
C10	0.02 0.40 P; 4.5 Sn; Rem. Cu
C11	6.0 7.5 Sn; 0.02–0.40 P; Rem. Cu
C12	6.0–7.5 Al; 1.0–2.5 (Fe + Mn + Ni); Rem. Cu
C12 Fe	6.5 8.5 Al; 2.5–3.5 Fe; Rem. Cu
C13	9.0 11.0 Al; 0.75–1.5 Fe; Rem. Cu
C16	10.0–12.0 Ni; 0.20–0.50 Ti; 1.5–1.8 Fe; 0.5 1.0 Mn; Rem. Cu
C18	30.0 32.0 Ni; 0.20–0.50 Ti; 0.40–1.0 Fe; 0.5–1.5 Mn; Rem. Cu
C20	8.0 9.5 Al; 1.5–3.5 Fe; 3.5–5.0 Ni; 0.5–2.0 Mn; Rem. Cu
C21	0.02 0.10 B; Rem. Cu
C22	7.0–8.5 Al; 2.0 4.0 Fe; 1.5 3.5 Ni; 11.0 14.0 Mn; Rem. Cu

Brasses or copper–zinc alloys. Zinc will dissolve in molten copper in all proportions and give a solution of a uniform character. Uniform solution can be obtained when solidified if the copper content is not less than about 60%. For example, 70% copper–30% zinc consists of a uniform crystal structure known as 'alpha' (α) solid solution and is shown in Fig. 2.29*a*. If the percentage of zinc is now increased to about 40%, a second constituent structure, rich in zinc, appears, known as 'beta' (β) solid solution, and these crystals appear as reddish in colour, and the brass now has a duplex structure as shown in Fig. 2.29*b*. These crystals are hard and increase the tensile strength of the brass but lower the ductility. The alpha-type brass, which can be obtained when the copper content has a minimum value of 63%, has good strength and ductility when cold and is used for sheet, strip, wire and tubes. The alpha–beta, e.g. 60% copper–40% zinc, is used for casting purposes, while from 57 to 61% copper types are suitable for hot rolling, extruding and stamping. Hence a great number of alloys of varying copper zinc content are available. Two groups, however, are of very great importance, as they occur so frequently:

(1) Cartridge brass: 70% copper and 30% zinc, written 70/30 brass.

(2) Yellow or Muntz metal: 60% copper and 40% zinc, written 60/40 brass.

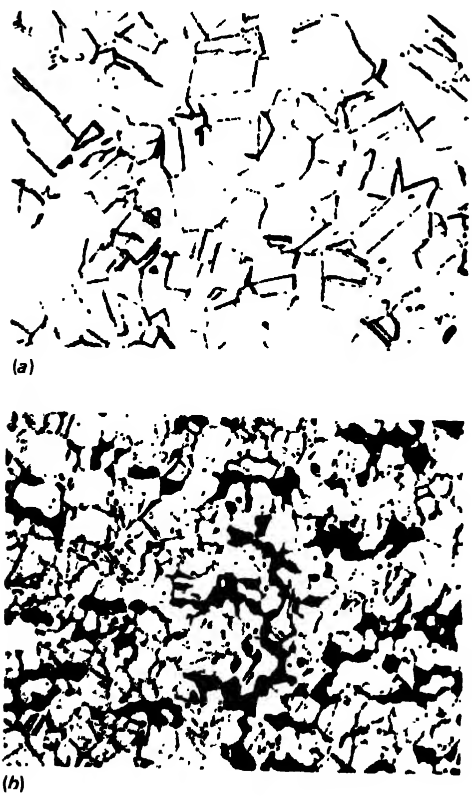
The table illustrates the composition and uses of various copper–zinc and copper–tin alloys.

Properties of brass. Brass is a copper-zinc alloy with a golden colour which can be easily cast, forged, rolled, pressed, drawn and machined. It has a good resistance to atmospheric and sea-water corrosion and therefore is used in the manufacture of parts exposed to these conditions. As the copper content in the brass is decreased, the colour changes from the reddish colour of copper to yellow and then pale yellow.

The density varies from 8200 to 8600 kg/m^3, depending on its composition. The heat and electrical conductivity decrease greatly as the zinc content increases, and the melting point is lowered as the copper content decreases, being about 920 °C for 70/30 brass.

Brass for brazing purposes can vary greatly in composition, depending upon the melting point required; for example, three brazing rod compositions are: 54% copper, 46% zinc; 50% copper, 50% zinc (melting at

Fig 2.29 (*a*) Rolled and annealed cartridge brass (70/30) This brass has a simple structure, containing only crystals of alpha solid solution, that is zinc dissolved in copper × 100 (*b*) Rolled and annealed yellow metal (60/40) This brass is a mixture of alpha crystals (white areas), and beta crystals (black areas), richer in zinc × 100



(*a*)

(*b*)

860 °C); and 85% copper, 15% zinc. The choice of the alloy therefore depends on the work for which it is required. For welding brass, the filler rod usually contains phosphorus or silicon, which act as deoxidizing agents, that is, they remove any oxygen from the weld.

As the copper content is reduced, there is a slight increase in the tensile strength.

Annealing. Examination of cold worked brass under the microscope shows that, as with copper, distortion of the crystals has taken place. When its temperature is raised to about 600 °C, recrystallization takes place and the crystals are very small. The rate of growth depends on the temperature, and the higher the temperature the larger the crystals or grains. The annealing time (as with steel) also affects their size. In over-annealed brass, having

Composition of copper–zinc and copper–tin alloys

Composition by weight Cu	Zn	Sn	Other elements	Uses
90	10			Gilding metal
88	2	10		Admiralty gun metal. Good casting properties and corrosion resistance. Widely used for pumps, valves, etc.
85	15			Architectural and decorative work.
80	20			
70	30			Cartridge brass. For deep drawing and where high strength and ductility are required
66	34			2:1 brass.
62–65	38–35			Common brass.
60	40			Yellow or Muntz metal. Works well when hot. For brass sheets and articles not requiring much cold work during manufacture
76	22		2 Al	Aluminium brass.
61–63.5	rem	1–1.4		Naval brass.
70–73	rem	1–1.5	0.02–0.06 As	Admiralty brass.
63–66	rem		0.75–1.5 Pb	Leaded brass, casts well. Easily hot stamped and extruded. Machines well.
61–64	rem		1.0–2.0 Pb	
58–60	rem		1.5–2.5 Pb	
58	38		Mn, Fe, Ni or Sn approx 4%	Manganese bronze, high-tensile alloys for castings and bearings.
Rem			2.7–3.5 Si 0.75–1.25 Mn	Silicon bronze.
Rem		3–4.5	0.02–0.4 P	3% phosphor bronze.
Rem		4.5–6.0	0.02–0.4 P	5% phosphor bronze.
Rem		6.0–7.5	0.02–0.4 P	7% phosphor bronze.

Note Material can be supplied as annealed (O), various tempers produced by cold work and partial annealing and indicated by ¼H, ½H, etc., spring tempers (SH and ESH), solution treated (W) and precipitation hardened (P)

large crystals, they may show up on the surface after cold working as an 'orange-peel' effect.

Annealing at too high a temperature may also cause pitting or deterioration of the surface by scaling.

Brass can be either quenched out in water or allowed to cool out slowly after annealing. If quenched, the surface scale is removed, but care must be taken with some brasses lest the ductility suffers.

Temper. Brass is tempered in the same way as copper, that is, by cold working. In the annealed condition it is 'soft temper' (60–80 Brinell). A little cold working brings it to 'half-hard temper' and further work gives it a 'hard temper' (150–170 Brinell). More cold working still, produces a 'spring-hard temper' with a Brinell number of 170–180.

Elasticity. The tensile strength of brass varies with the amount of cold working, and it is sufficiently elastic to allow of its being used as springs when in the spring-hard temper condition.

Bronzes or copper–tin alloys

Gunmetals are zinc-containing bronzes, e.g. 88% Cu, 10% Sn, 2% Zn. Wrought phosphor bronzes contain up to 8% tin and up to 0.4% phosphorus, while cast forms contain at least 10% tin with additions of lead to promote free machining and pressure tightness.

Gunmetal was chiefly used, as its name suggests, for Admiralty and Army Ordnance work, but is now used chiefly where resistance against corrosion together with strength is required. Lead bronze has lead added to improve its properties as a bearing surface and to increase its machinability.

Phosphor bronze has largely replaced the older bearing bronze for bearings owing to its increased resistance to wear. Phosphorus, when added to the copper–tin bronze, helps greatly to remove the impurities, since it is a powerful reducing agent and the molten metal is made much purer.

Bronze welding rods of copper–tin and copper–zinc composition are very much used as filler rods and electrodes in welding. They can be used for the welding of steel, cast iron, brass, bronze and copper, and have several advantages in many cases over autogenous welding since, because of their lower melting point, they introduce less heat during the welding operation. Manganese bronze can be considered as a high-tensile brass.

Nickel and nickel alloys

Nickel is a greyish-white metal melting at 1450°C, has a specific gravity of 8.8, and has a coefficient of linear expansion of 0.000 013 per degree C.

Nickel and nickel alloys

Material	Major constituents	Applications
Nickel	almost pure nickel	High resistance to corrosion in contact with caustic alkalis, dry halogen gases and organic compounds generally.
MONEL* alloys	nickel, copper	Has good corrosion resistance with good mechanical properties. A variation responds to thermal hardening of the precipitation type and has good corrosion resistance, with the mechanical properties of heat-treatable alloy steels.
INCONEL* alloys	nickel, chromium, iron.	Is oxidation-resistant at high temperatures with good mechanical properties and is resistant to food acids. Widely used for heat treatment and furnace equipment.
	nickel, chromium, iron with additions of molybdenum and niobium.	High level of mechanical properties without the need for heat treatment. Good oxidation resistance and resists corrosive attack by many media. Other variations are age-hardenable with high strength at elevated temperatures, have outstanding weldability and can be welded in the heat-treated condition.
INCOLOY* alloys	nickel, chromium, iron.	Oxidation-resistant at elevated temperatures with good mechanical properties. Variations with a lower silicon content used for pyrolysis of hydrocarbons as in cracking or reforming operations in the petroleum industry.
	nickel, chromium, iron with copper and molybdenum additions	Resistant to hot acid and oxidizing conditions, e.g. nitric–sulphuric–phosphoric acid mixtures.
NIMONIC* alloys	nickel, chromium. nickel, chromium, cobalt. nickel, chromium, iron.	Used for gas turbine parts, heat treatment and other purposes where both oxidation resistance and high-temperature mechanical properties are required.
BRIGHTRAY* alloys	nickel, chromium. nickel, chromium, iron.	Heating elements of electric furnaces, etc.
NILO* alloys	nickel, iron.	These have a controlled low and intermediate coefficient of thermal expansion and are used in machine parts, thermostats and glass-to-metal seals.

MONEL, INCOLOY, INCONEL, etc. are trademarks of the Inco family of companies. Various alloys in each group, having particular compositions for specific purposes, are indicated by an alloy number, thus MONEL* alloy 400, INCONEL* alloy 600, INCOLOY* alloy 825 etc.

It resists caustic alkalis, ammonia, salt solutions and organic acids, and is used widely in chemical engineering for vats, stills, autoclaves, pumps, etc. When molten, it absorbs (1) carbon, forming nickel carbide (Ni_3C), which forms graphite on cooling; (2) oxygen, forming nickel oxide (NiO), which makes the nickel very brittle, and (3) sulphur, forming nickel sulphide (NiS).

Magnesium and manganese are added to nickel in order to deoxidize it and render it more malleable.

Nickel is widely used as an alloying element in the production of alloy steels, improving the tensile strength and toughness of the steel, and is used in cast iron for the same purpose. In conjunction with chromium it gives the range of stainless steels.

Copper–nickel alloys

Nickel and copper are soluble in each other in all proportions to give a range of cupro-nickels which are ductile and can be hot and cold worked. The more important alloys are the following:

90% Cu, 10% Ni, used for heat exchangers for marine, power, chemical and petrochemical use; feed water heaters, condensers, evaporators, coolers, radiators, etc.

80% Cu, 20% Ni, used for heat exchangers, electrical components, deep-drawn pressings and decorative parts.

70% Cu, 30% Ni, which has the best corrosion resistance to sea and other corrosive waters and is used for heat exchangers and other applications given for 90/10% alloy.

The alloys used for resistance to corrosion usually have additions of iron (0.5–2.0%) and manganese (0.5–1.5%), while alloys for electrical uses are free from iron and have only about 0.2% Mn. The actual composition of one such alloy is 68% Ni 29% Cu 1·5% Fe.

Other alloys are: 75% Cu, 25% Ni, used for coinage; and nickel silvers, which contain 10–30% Ni, 55–63% Cu with the balance zinc and are extensively used for cutlery and tableware of all kinds, being easily electroplated (EPNS). Nickel is added to brass and aluminium bronze to improve corrosion resistance.

Aluminium

Aluminium is prepared by electrolysis from the mineral *bauxite*, which is a mixture of the oxides of aluminium, silicon and iron.

The aluminium oxide, or alumina as it is called, is made to combine with caustic soda to form sodium aluminate, thus:

alumina + caustic soda → sodium aluminate + water

$$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$$

This solution of sodium aluminate is diluted and filtered to remove iron oxide, and aluminium hydroxide is precipitated. This is dried and calcined leaving aluminium oxide (Al_2O_3). The aluminium oxide is placed together with cryolite (Na_3AlF_6) and sometimes fluorspar (CaF_2) into a cell lined with carbon, forming the cathode or negative pole of the direct current circuit. Carbon anodes form the positive pole and hang down into the mixture. The p.d. across the cell is about 6 volts and the current which passes through the mixture and fuses it may be up to 100 000 amperes. As the current flows, the cryolite is electrolysed, aluminium is set free and is tapped off from the bottom of the cell, while the fluorine produced reacts with alumina, forming aluminium fluoride again. Because such large currents are involved, aluminium production is carried out near cheap sources of electrical power.

Aluminium prepared in this way is between 99 and 99.9% pure, iron and silicon being the chief impurities. In this state it is used for making sheets for car bodies, cooking utensils, etc., and for alloying with other metals. In the 99.5%-and-over state of purity it is used for electrical conductors and other work of specialized nature.

Properties of aluminium. Pure aluminium is a whitish-coloured metal with a density of 2.6898 g/cm^3 (2700 kg/m^3), that is, it weighs less, volume for volume, than one-third the weight of copper (8.96 g/cm^3) and just more than one-third that of iron (7.9 g/cm^3). Its melting point is 660 °C (boiling point 2480 °C) and its tensile strength varies from 60 to 140 N/mm^2 (MPa) according to the purity and the amount of cold work performed on it.

It casts well, has high ductility and can be hammered and rolled into rod and sheet form, etc., and extruded into wire. In contact with air a thin film of oxide (alumina) forms on the surface. In non-corrosive conditions the film is thin and almost invisible but in corrosive conditions it may appear as a grey-coloured coat helping to prevent further corrosion. This oxide is removed by fluxes in oxy-acetylene welding but nowadays welding is easily performed by the TIG or MIG processes using inert gas shielding (argon or helium), by electron beam and laser, and most alloys can be resistance welded. Some alloys can be brazed using an aluminium silicon filler rod containing up to 10% silicon.

Aluminium is a good conductor of heat and electricity and pure aluminium may be drawn into wire for power cables. For transmission lines the strands are wound over a stranded steel core to give the required strength. Weight for weight aluminium is a better conductor than copper.

The process known as anodising produces a relatively hard and thick film of oxide on the surface. The film can be dyed any colour and the thicker the film produced, the greater the corrosion resistance.

Aluminium and its alloys. Aluminium and its alloys can be divided into two groups:

(1) casting alloys
(2) wrought alloys

It is these latter which are of greatest importance to the welder. Wrought alloys may be further divided into two groups according to the treatment required in order to improve their mechanical properties: (*a*) heat-treatable; (*b*) non-heat-treatable or work-hardening; and cold work including rolling, drawing and stamping, etc., improves the mechanical properties of these alloys and increases the tensile strength and hardness. The aluminium–silicon alloys containing 10–15% silicon (a eutectic is formed with 11.7% silicon) are very fluid when molten, cast well and have considerable strength, ductility and resistance to corrosion, with small contraction on solidification. The addition of magnesium, manganese or both gives a range of work hardening alloys, while the addition of copper, magnesium and silicon gives a range of heat-treatable alloys which age-harden due to the formation of intermetallic compounds, and they have a high strength–weight ratio. The aluminium–zinc–magnesium–copper alloys, after full heat treatment give the highest strength–weight ratio.

Heat treatment. The purpose of heat treatment is to increase strength and hardness of the alloy. By the addition of small percentages of elements such as copper, magnesium, silicon, zinc, etc., intermetallic compounds are formed and the mechanical properties of the alloy are improved. Some alloys are used in the 'as cast' or wrought condition while others are modified by heat treatment and/or cold working.

Solution treatment. The heat-treatable alloy is raised in temperature to between 425 °C and 540 °C depending upon the alloy. The relatively hard constituents formed by the addition of the alloying elements are taken into solid solution and the alloy is then quenched (e.g. in water). The constituents remain in solid solution but the alloy is soft and unstable. As time passes the constituents precipitate into a more uniform pattern in the alloy and the strength and hardness increase. This is known as natural age-hardening or precipitation hardening and can be from a few hours to many months. Any forming should be performed immediately after quenching, before any age-hardening has had time to affect the alloy. Some alloys harden slowly at room temperature and the precipitation can be speeded by heating the alloy within the range 100–200 °C for a given period, termed artificial age-hardening.

Annealing. Annealing softens the alloy and may be used after hardening by cold work or heat treatment. To avoid excessive grain growth the alloy should be heated to the annealing temperature as rapidly as possible and held there only as long as required since grain growth reduces the strength. For work-hardening alloys the temperature range for annealing is 360–425 °C for about 20 minutes, while heat-treatable alloys should be raised to 350–370 °C. Cooling should be in air at not too rapid a rate.

Stabilizing. This consists of heating the alloy to a temperature of about 250 °C and then cooling slowly, the exact temperature depending upon the alloy and its future use. Residual internal stresses are relieved by this treatment.

Classification of aluminium and its alloys

Alloy and heat-treatment designations. Casting alloys (BS 1490) are prefaced by the letters LM and numbered 1–30, although some have now been withdrawn. Suffixes after the alloy number indicate the condition of the casting thus:

M	as cast
TB	solution heat treated and naturally aged
TB7	solution heat treated and stabilized
TE	artificially aged
TF	solution heat treated and artificially aged
TF7	solution heat treated, artificially aged and stabilized
TS	thermally stress relieved.

Wrought products. These include bar, cold rolled plate, drawn and extruded tube, hot rolled plate, rivet and screw stock, sheet, strip and wire, etc. The mechanical working on the cast metal increases the strength but decreases the ductility. It is in this section that most of the alloys welded occur.

Alloy and temper designations for wrought aluminium (BS 1471). This is an international four digit system of which the first digit indicates the alloy group according to the major alloying elements thus:

1xxx	aluminium of 99.00% minimum purity	5xxx	magnesium
		6xxx	magnesium and silicon
2xxx	copper	7xxx	zinc
3xxx	manganese	8xxx	other elements
4xxx	silicon	9xxx	unused series

The last two digits in group 1xxx show the minimum percentage of aluminium. Thus 1050 is aluminium with a purity (minimum) of 99.50%.

The second digit shows modifications in impurity limits or the addition of alloying elements: the digits 1 9 used consecutively indicate modifications to the alloy. If the second digit is zero, the alloy is unalloyed and has only natural limited impurities.

Four-digit nomenclature referred to previous standard designations

BS and International Designation	Old BS Designation	ISO Designation
1080A	1A	Al 99.8
1050A	1B	Al 99.5
1200	1C	Al 99.0
1350 (electrical purity)	1E	Al 99.5
2011	FC1	Al Cu 5.5 Pb Bi
2014A	H15	Al Cu 4 Si Mg
2031	H12	Al Cu 2 Ni 1 Mg Fe Si
2618A	H16	Al Cu 2 Mg 1.5 Fe 1 Ni 1
3103	N3	Al Mn 1
3105	N31	Al Mn Mg
4043A	N21	Al Si 5
4047A	N2	Al Si 12
5005	N41	Al Mg 1
5056A	N6	Al Mg 5
5083	N8	Al Mg 4.5 Mn
5154A	N5	Al Mg 3.5
5251	N4	Al Mg 2
5454	N51	Al Mg 3 Mn
5554	N52	Al Mg 3 Mn
5556A	N61	Al Mg 5.2 Mn Cr
6061	H20	Al Mg 1 Si Cu
6063	H9	Al Mg Si
6082	H30	Al Si 1 Mg Mn
6101A	91E	Al Mg Si
6463	BTR E6	Al Mg Si
7020	H17	Al Zn 4.5 Mg 1

In groups 2xxx to 8xxx the last two of the four digits only serve to identify the different alloys in the groups. As before the second digit indicates alloy modifications and if it is zero it indicates the original alloy.

There are national variations for some alloys, identified by a letter after the four-numeral designation. The letters are in alphabetical order beginning with A for the first national variation registered, but omitting I, O and Q. An example is 1050A. The accompanying table which compares this BS and international designation with the old BS and ISO designations will make this clear.

Cold work

Temper. This denotes the amount of cold work done on the alloy and has the prefix H followed by (in the UK system) the numbers 1 to 8 indicating increasing strength. The letter O indicates the soft, fully annealed condition and the letter M (F in the US) indicates the material 'as manufactured'.

For example (see table) 3103-O is an aluminium manganese alloy in the annealed condition while 3103-H6 indicates the same alloy in the three-quarters hard temper.

The American system has a further figure after the letter H. The figure 1 indicates that the temper was obtained by strain hardening. For example H 16 indicates three-quarters hard temper obtained by strain hardening. The figure 2 indicates that the temper was obtained by strain hardening more than that required and then partially annealing the alloy. The figure 3 indicates that the mechanical properties after cold work are stabilized by a low temperature heat treatment - used only for alloys which otherwise would naturally age-soften at room temperature.

Comparison of UK and US systems

UK symbol	Description	US system
H	Strain hardened, non-heat-treatable material	H
No equivalent	Strain hardened only	H 1
No equivalent	Strain hardened and partially annealed.	H 2
No equivalent	Strain hardened and stabilized	H 3
H 2	Quarter hard	H 12, H 22, H 32
H 4	Half hard.	H 14, H 24, H 34
H 6	Three-quarters hard	H 16, H 26, H 36
H 8	Fully hard (hardest commercially practicable temper)	H 18, H 28, H 38
No equivalent	A special hard temper (for special applications).	H 19
M	As manufactured	F
O	Annealed soft	O

Symbols used for heat treatment

There are five basic heat-treatment tempers in the UK system and ten basic heat treatment tempers in the US system preceded by the letter T for thermal treatment.

UK symbol	Description	US symbol
—	Cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.	T1
—	Cooled from an elevated temperature shaping process, cool worked and naturally aged to a substantially stable condition.	T2
T D	Solution heat treated, cold worked and naturally aged to a stable condition.	T3
T B	Solution heat treated and naturally aged to a substantially stable condition.	T4
T E	Cooled from an elevated temperature shaping process and then artificially aged.	T5
T F	Solution heat treated and then artificially aged	T6
—	Solution heat treated and stabilized.	T7
T H	Solution heat treated, cold worked and then artificially aged.	T8
—	Solution heat treated, artificially aged and then cold worked.	T9
—	Cooled from an elevated temperature shaping process, cold worked and then artificially aged.	T10

Note: Certain other digits are assigned for specific conditions such as stress relieved tempers and can be referred to in the book *Aluminium and its Alloys*, published by The Aluminium Federation (ALFED).

Magnesium

Magnesium is an element of specific gravity 1.8, but although it has a relatively high specific heat capacity (1.1×10^3 joules per kg°C), the volume heat capacity is only $\frac{3}{4}$ of that of aluminium. It melts at 651 °C and its specific latent heat of fusion is lower than that of aluminium, so that for a given section the heat required to melt magnesium is about $\frac{2}{3}$ that required for an equal weight of aluminium. It has a high coefficient of expansion and a high thermal conductivity so that the danger of distortion is always

Percentage composition of typical aluminium alloys for TIG and MIG welding. In each case remainder Al.

Old classification	Alloy designation	Si	Fe	Cu	Mn	Mg	Cr	Zn	
1A	1080A	0.15	0.15	0.03	0.02	0.02	—	0.06	Ga 0.03
1B	1050A	0.25	0.4	0.05	0.05	0.05	—	0.07	
N3	3103	0.5	0.7	0.10	0.9–1.5	0.3	0.1	0.2	Zr + Ti 0.1
N21	4043A	4.5–6.0	0.6	0.3	0.15	0.2	—	0.1	Be 0.0008
N2	4047A	11.0–13.0	0.6	0.3	0.15	0.1	—	0.2	
N6	5056A	0.4	0.5	0.1	01 –0.6	4.5–5.6	0.2	0.2	Mn + Cr 0.1-0.6
—	5356	0.25	0.4	0.1	0.05–0.2	4.5–5.5	0.05–0.2	0.2	Be 0.0008
N5	5154A	0.5	0.5	0.1	0.1–0.5	3.1–3.9	0.25	0.2	Mn + Cr 0.1–0.5
N4	5251	0.4	0.5	0.15	0.1–0.5	1.7–2.4	0.15	0.15	
N52	5554	0.25	0.4	0.1	0.5–1.0	2.4–3.0	0.05–0.2	0.25	Be 0.0008
N61	5556A	0.25	0.4	0.1	0.6–1.0	5.0–5.5	0.05–0.2	0.2	
H20	6061	0.4–0.8	0.7	0.15–0.4	0.15	0.8–1.2	0.04 0.35	0.25	
H9	6063	0.2–0.6	0.35	0.1	0.1	0.45–0.9	0.1	0.1	

(See also MIG and TIG welding of aluminium alloys, pp. 434–82 and 489–531.)

Magnesium alloys. Composition (major alloying elements) and properties.

Alloy	Major alloying elements, %	Condition	Tensile st, N/mm^2	Elongation, %	Hardness Brinell	Properties
Wrought alloys						
ZTY	Th 0.8, Zn 0.6, Zr 0.6	Extruded forgings	200–230	6–8	50–60	Creep resistant to 350 °C. Weldable
ZM21	Zn 2.0, Mn 1.0	Extruded bars, plate, tubes, etc.	220	8–10	50–60	Medium strength sheet and extrusion alloy. Weldable, gas-shielded metal arc.
AZ80	Al 8.5, Zn 0.5, Mn 0.3	Forgings Ppt treated	290	6	60	High strength alloy for forgings of simple design.
AZM	Al 6.0, Zn 1.0, Mn 0.3	Extruded bars, sections, etc.	250	7	55–70	General purpose alloy. Gas and arc weldable.
AZ31	Al 3.0, Zn 1.0, Mn 0.3	Sheet, bars, extruded sections.	220–250	5–12	50–70	Medium strength alloy, sheet, tube, etc. Weldable.
AM503	Mn 1.5	Sheet, plate, extruded sections, etc.	190–230	3–5	35–55	Low strength general purpose alloy, good corrosion resistance. Weldable.
Casting alloys						
ZRE1	Zn 2.5, Zr 0.6, RE 3.0	Ppt. treated, sand cast	140	3	50–60	Creep resistant to 250 °C. Pressure tight. Weldable.
RZ5	Zn 4.2, Zr 0.7, RE 1.3	Ppt. treated, sand cast	200	3	55–70	Easily cast, strong at elevated temp : pressure tight. Weldable
ZE63	Zn 5.8, Zr 0.7, RE 2.5	Soln and Ppt. treated, sand cast	275	5	60–85	Casts well. Pressure tight. Weldable.

ZT1	Th 3.0, Zn 2.2, Zr 0.7	Ppt. treated, sand cast	185	5	50–60	Creep resistant to 350 °C. Pressure tight. Weldable.
TZ6	Zn 5.5, Th 1.8, Zr 0.7	Ppt. treated, sand cast	255	5	65–75	Casts as RZ5 but stronger. Pressure tight, Weldable.
OH21A	Ag 2.5, Th 1.0, Zr 0.7. Nd rich RE 1.0	Soln and Ppt. treated, sand cast	240	2	70–90	Heat treated alloy, creep resistant: High yield strength to 300 °C. Pressure tight. Weldable.
MSR-B	Ag 2.5, Zr 0.6, Nd rich RE 2.5	Soln and Ppt. treated, sand cast	240	2	70–90	Heat treatable alloy. High yield strength to 250 °C. Pressure tight. Weldable.
A8	Al 8.0, Zn 0.5, Mn 0.3	Soln treated, sand cast	200	7	50–60	Good foundry properties, good ductility and shock resistant.

In addition the following alloys have been introduced:

Wrought	ZC61	Zn 6.0%, Cu 1.0%.
Casting	QH2LA	Zr 0.7%, Ag 2.6%, Th 1.0%, Nd 1.0%. Weldable TIG.
	EQ21A	Zr 0.7%, Ag 1.5%, Nd 2.0% Weldable TIG.
	ZE63A	Zr 0.7%, Zn 5.8%, RE 2.5%. Weldable TIG.
	Zr55	Zr 0.55%.

Ppt = precipitation, soln = solution, RE = rare earths.

present. It oxidizes rapidly in air above its melting point and though it burns with an intense white flame to form magnesium oxide there is little danger of fire during the welding process (TIG and MIG).

As will be seen from the table the chief alloying elements are zinc, aluminium, silver, manganese, zirconium, thorium and the rare earths; the alloying elements improving casting properties, tensile strength, elongation, hardness, etc., as required.

From the table it will be noticed that most of the alloys are weldable by the gas shielded metal arc process. The heat-treatable alloys are solution and precipitation treated in the same way as the aluminium alloys.

As yet standard designations are not equivalent in the British and American Systems, the US having adopted their own Unified Numbering System (UNS) whereas the UK is using the ISO system. The standards applicable are:

USA/ASTM	B80	*Sand castings*
	B90	*Sheet and plate*
	B91	*Forgings*
	B92	*Ingots for remelting*
	B93–94	*Ingots for sand casting, die casting, etc.*
	B1707	*Extruded bars and sections*
UK/BSI	2970	*Ingots and castings*
	3370	*Plate, sheet and strip*
	3372	*Forgings*
	3373	*Extruded bars and sections*
	2901	*Part 4. Filler rods for TIG welding*
	3019	*Part 1. Filler rods for TIG welding*

Stress and distortion in welding

Stresses set up in welding

In the welding process, whether electric arc or oxy-acetylene, we have a molten pool of metal which consists partly of the parent metal melted or fused from the side of the joint, and partly of the electrode or filler rod.

As welding proceeds this pool travels along and heat is lost by conduction and radiation, resulting in cooling of the joint. The cooling takes place with varying rapidity, depending on many factors such as size of work, quantity of weld metal being deposited, thermal conductivity of the parent metal and the melting point and specific heat of the weld metal.

As the weld proceeds we have areas surrounding the weld in varying conditions of expansion and contraction, and thus a varying set of forces

will be set up in the weld and parent metal. When the weld has cooled, these forces which still remain, due to varying conditions of expansion and contraction, are called *residual stresses* and they are not due to any external load but to internal forces.

The stresses will cause a certain deformation of the joint. This deformation can be of two kinds: (1) elastic deformation, or (2) plastic deformation.

If the joint recovers its original shape upon removal of the stresses, it has suffered elastic deformation. If, however, it remains permanently distorted, it has suffered plastic deformation. The process of removal of these residual stresses is termed *stress relieving*.

Stresses are set up in plates and bars during manufacture due to rolling and forging. These stresses may be partly reduced during the process of welding, since the metal will be heated and thus cause some of these stresses to disappear. This may consequently reduce the amount of distortion which would otherwise occur.

Stresses, with their accompanying strains, caused in the welding process, are thus of two types:

(1) Those that occur while the weld is being made but which disappear on cooling.

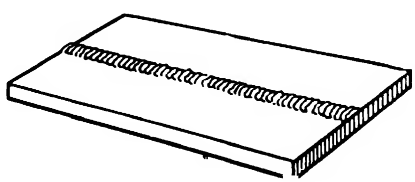
(2) Those that remain after the weld has cooled.

If the welded plates are free to move, the second causes distortion. If the plates are rigid, the stresses remain as residual stresses. Thus we have to consider two problems: how to prevent distortion, and how to relieve the stress.

Distortion is dependent on many factors, and the following experiment will illustrate this.

Take two steel plates about 150 mm × 35 mm × 8 mm. Deposit a straight layer of weld metal with the arc across one face, using a small current and a small electrode. This will give a narrow built-up layer. No distortion takes place when the plate cools (Fig. 2.30). Now deposit a layer on the second plate in the same way, using a larger size electrode and a heavier current. This will give a wider and deeper layer.

Fig 2.30



On cooling, the plate distorts and bends upwards with the weld on the inside of the bend (Fig. 2.31). In the first operation the quantity of heat given to the plate was small, due to the small mass of weld laid down. Thus contraction forces were small, and no distortion occurred. In the second operation, much more weld metal was laid down, resulting in a much higher temperature of the weld on the upper side of the plate. On cooling, the upper side contracted therefore more than the lower, and due to the pull of the contracting line of weld metal, distortion occurred. Evidently, if another layer of metal was laid on the second plate in the same way, increased distortion would occur. Thus from experience we find that:

(1) An increase in speed tends to increase distortion because a larger flame (in oxy-acetylene), and a larger diameter electrode and increased current setting (in electric arc) have to be used, increasing the amount of localized heat.

(2) The greater the number of layers of weld metal deposited the greater the distortion.

Let us now consider some typical examples of distortion and practical methods of avoiding it.

Two plates, prepared with a V joint, are welded as shown. On cooling, the plates will be found to have distorted by bending upwards (Fig. 2.32).

Again, suppose one plate is set at right angles to the other and a fillet weld is made as shown. On cooling, it will be found that the plates have pulled over as shown and are no longer at right angles to each other (Fig. 2.33).

This type of distortion is very common and can be prevented in two ways:

(1) Set the plates at a slight angle to each other, in the opposite direction to that in which distortion will occur so that, when cool, the plates are in correct alignment.

Fig 2.31

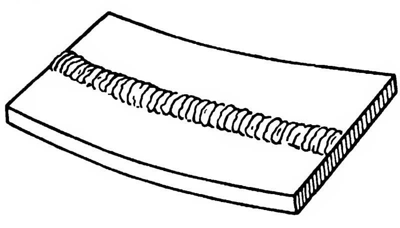


Fig. 2.32

(2) Clamp the plates firmly in a fixture or vice so as to prevent their movement.

Since we have seen that the amount of distortion depends on several factors, such as speed of welding and number of layers, the amount of bias to be given to the plates in the opposite direction will be purely a matter of experience.

If the plates are fixed in a vice or jig, so as to prevent movement, the weld metal or parent metal must stretch or give, instead of the plates distorting. Thus there is more danger in this case that residual stresses will be set up in the joint.

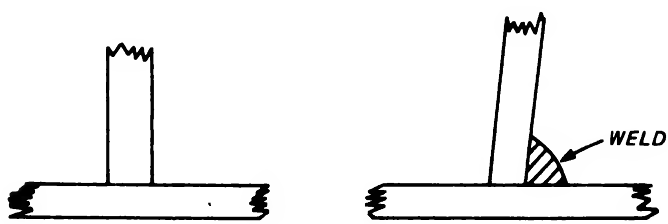
A very familiar case is the building up of a bar or shaft. Here it is essential to keep the shaft as straight as possible during and after welding so as to reduce machining operations. Evidently, also, neither of the two methods of avoiding distortion given above can be employed. In this case distortion can be reduced to a minimum by first welding a deposit on one side of the shaft, and then turning the shaft through 180° and welding a deposit on the opposite diameter. Then weld on two diameters at right angles to these, and so on, as shown in Fig. 2.34. The contraction due to layer 2 will counteract that due to layer 1, layer 4 will counteract layer 3, and so on.

If two flat plates are being butt welded together as shown, after having been set slightly apart to begin with, it is found that the plates will tend to come together as the welding proceeds.

This can be prevented either by tack welding each end before commencing welding operations, clamping the plates in a jig to prevent them moving, or putting a wedge between them to prevent them moving inwards (Fig. 2.35). The disadvantage of tack welding is that it is apt to impair the appearance of the finished weld by producing an irregularity where the weld metal is run over it on finishing the run.

Step welding or back stepping is often used to reduce distortion. In this method the line of welded metal is broken up into short lengths, each length ending where the other began. This has the effect of reducing the heat in any one section of the plate, and it will be seen that in this way when the finish of

Fig 2.33



step 2 meets the beginning of step 1 we have an expansion and contraction area next to each other helping to neutralize each other's effect (Fig. 2.36).

In the arc welding of cast iron without pre-heating, especially where good alignment at the end of the welding process is essential, beware of trying to limit the tendency to distort while welding, by tacking too rigidly, as this will frequently result in cracking at the weakest section, often soon after welding has been commenced. Rather set the parts in position so that after welding they have come naturally into line and thus avoid the setting up of internal stresses. Practical experience will enable the operator to decide how to align the parts to achieve this end.

In *skip welding* a short length of weld metal is deposited in one part of the seam, then the next length is done some distance away, keeping the sections as far away from each other as possible, thus localizing the heat (Fig. 2.37). This method is very successful in the arc welding of cast iron.

To avoid distorting during fillet welding the welds can be done in short lengths alternately on either side of the leg of the T, as shown in Fig. 2.38, the welds being either opposite each other as in the sketch (*a*) or alternating as in the sketch (*b*). It is evident that a great deal can be done by the operator to minimize the effects of distortion.

In the case of cast iron, however, still greater care is needed, because whereas when welding ductile metals there is the plasticity of the parent metal and weld metal to cause a certain yielding to any stresses set up, cast

Fig 2.34

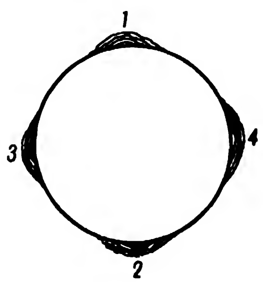
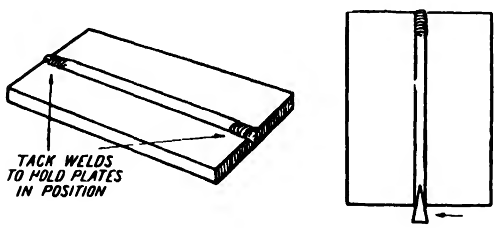


Fig. 2.35



iron, because of its lack of ductility, will easily fracture before it will distort, unless the greatest care is taken. This has previously been mentioned in the effects of expansion and contraction.

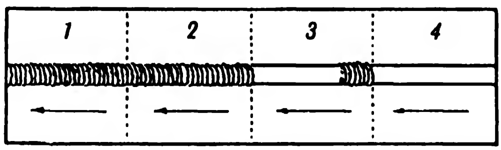
In the welding of cast iron with the blowpipe, pre-heating is always necessary unless the casting is of the simplest shape. The casting to be welded is placed preferably in a muffle furnace and its temperature raised gradually to red heat.

For smaller jobs pre-heating may be carefully carried out by two or more blowpipes and the casting allowed to cool out in the hot embers of a forge.

Residual stresses and methods of stress relieving

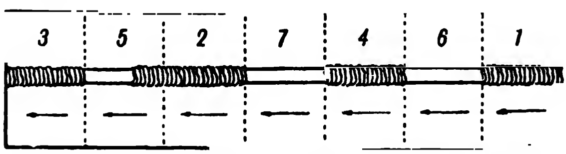
In addition to these precautions, however, the following experiment will show how necessary it is to follow the correct welding procedure to prevent fracture. Three cast-iron plates are placed as shown in Fig. 2.39

Fig. 2.36



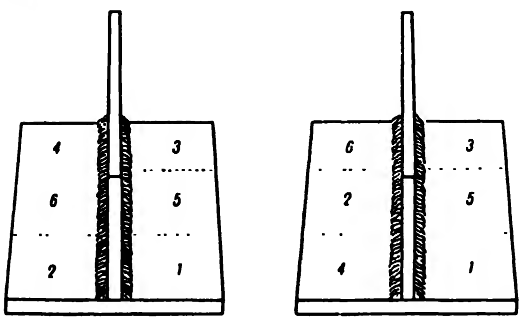
ARROWS AND NUMBERS SHOW DIRECTION AND ORDER OF WELDING

Fig. 2.37



ARROWS AND NUMBERS SHOW DIRECTION AND ORDER OF WELDING

Fig. 2.38



(a) (b)

and are first welded along the seam *A–B*. No cracking takes place, because they are free to expand and contract.

If we now begin at *D* and weld to *C*, that is, from the free end to the fixed end, cracking will in all probability occur; whereas, if we weld from *C* to *D*, no cracking occurs.

When we weld from *D* to *C* the ends *D* and *C* are rigid and thus there is no freedom in the joint. Stresses are set up in cooling, giving tendency to fracture. Welding from *C* to *D*, that is, from fixed to free end, the plates are able to retain a certain amount of movement regarding each other, as a result of which the stresses set up on cooling are much less and fracture is avoided. Thus, always weld away from a fixed end to a free end in order to reduce residual stress.

Peening. Peening consists of lightly hammering the weld and/or the surrounding parent metal in order to relieve stresses present and to consolidate the structure of the metal. It may be carried out while the weld is still hot or immediately the weld has cooled.

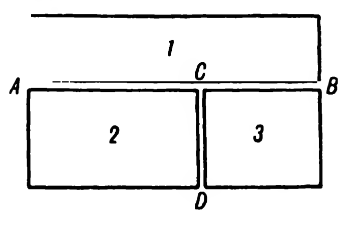
A great deal of controversy exists as to whether peening is advantageous or not. Some engineers advocate it because it reduces the residual stresses, others oppose it because other stresses are set up and the ductility of the weld metal suffers. If done reasonably, however, it undoubtedly is of value in certain instances. For example, in the arc welding of cast iron the risk of fracture is definitely reduced if the short beads of weld metal are lightly peened *immediately* after they have been laid. Care must be taken in peening hot metal that slag particles are not driven under the surface.

Pre- and post-heat treatment

The energy for heat treatment may be provided by oil, propane or natural gas or electricity and the heat may be applied locally, or the welded parts if not too large, may be totally enclosed in a furnace.

The temperature in localized pre-heating, which usually does not exceed 250 °C, should extend for at least 75–80 mm on each side of the welded joint. Post-heat temperatures, usually in the range 590–760 °C, reduce

Fig. 2.39

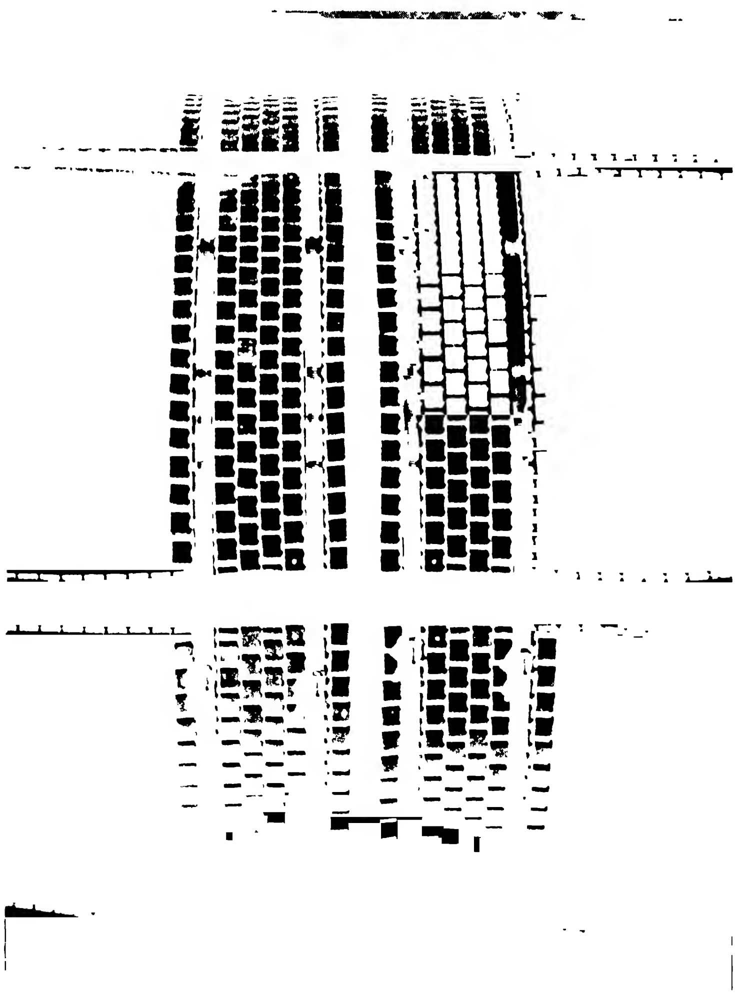


internal stresses and help to soften hardened areas in the HAZ. The work is heated to a given temperature, held at this temperature for a given 'soaking' time, and then allowed to cool, both heating and cooling being subject to a controlled temperature gradient such as 100–200 °C per hour for thicknesses up to 25 mm and slower rates for thicker plate, depending upon the code being followed (ASME, BS, CEGB, DIN).

Localized heat

This can be applied using flexible insulated pad and finger electrical heaters (Fig. 2.40*a*). These are available in a variety of shapes with

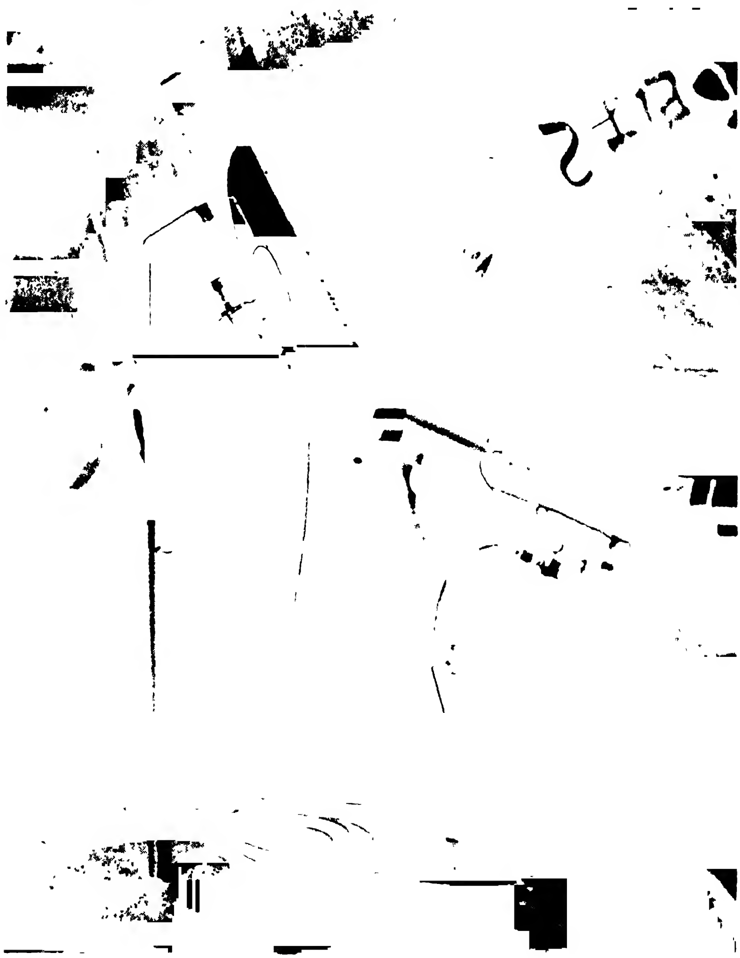
Fig 2.40 (*a*) Flexible ceramic pad heaters strapped round a circular closing seam on a 1.2 m diameter vessel with wall thickness of 25 mm.



the elements insulated with ceramic beads and supplied from the welding power source or an auxiliary transformer at 60–80 V.

The pads are connected in parallel as required and are covered over with insulating material to conserve heat. Heat can also be applied locally by gas or oil burners, as for example on circumferential and longitudinal vessel seams (Fig. 2.40*b*). There is now available a rectangular ceramic plaque, protected by an Inconel mesh grill. The plaques each have hundreds of tiny holes and as the gas–air mixture emerges onto the front face of them it is ignited and burns on the plaque surface, which becomes intensely hot (1000 °C), and if these are placed 50–75 mm from the seam to be heated heat is transferred mainly by radiation and rapid heating of the work is achieved

Fig. 2.40. (*b*) Surface combustion units propane or natural gas set up for preheating rotating seams.



up to 250 °C. The burners operate in all positions and can be supplied with magnetic feet for easy attachment to the work.

Furnaces

The older furnaces were of firebrick, fired with gas or oil or electrically heated, and were very heavy. The modern 'top hat' furnace has a hearth with electric heating elements laid in ceramic fibre over which fits a light steel framework insulated inside with mineral wool and ceramic fibre. This furnace is of light thermal mass and can be quickly loaded or unloaded by lifting the unit, consisting of side walls and top, clear of the hearth with its load. The furnace can be heated overnight to take advantage of the lower charges for electrical power, the temperature control of the units being automatic.

These furnaces operate up to 650 °C. If higher temperatures up to 1050 °C are required, additional elements can be added to the furnace sides with loadings up to 1200 kW. Top hat furnaces are made in a variety of sizes including multiple hearths in which the top hat can be moved onto one hearth while the other is being loaded or unloaded. For furnaces of over 150 m^3 in volume, with their own gas trains, gas firing is very popular. Burners are chassis-mounted and arranged so that they fire down the side walls. As they are of high-velocity gas they avoid direct impingement on the parts being heated and temperatures are evenly distributed by the high-velocity action of the burners.

Temperatures of pre- or post-heat are generally measured by thermo-couple pyrometers and it is very important that the junction of the ends of the thermo-couple wires should be firmly attached to the place where the temperature is to be measured. Clips welded on in the required position and to which the junction is attached are used but when elements are placed over the junction it is possible for a temperature greater than that which actually exists in the work to be indicated due to the proximity of the heating element to the clip joint. A method to avoid this danger is to weld each of the couple wires to the pipe, spaced a maximum of 6 mm apart, by means of a capacitor discharge weld. The weld is easy to make using an auxiliary capacitor unit and reduces the possibility of erroneous readings. The only consumable is the thermo-couple wire, about 150 mm of which is cut off after each operation.

Summary of foregoing section:

Factors affecting distortion and residual stresses

(1) If the expansion which occurs when a metal is heated is resisted, deformation will occur.

(2) When the contraction which occurs on cooling is resisted, a stress is applied.
(3) If this applied stress causes movement, distortion occurs.
(4) If this applied stress causes no movement, it is left as a residual stress.

Methods of reducing distortion

(1) Decrease the welding speed, using the smallest flame (in oxy-acetylene) and the largest diameter electrode and lowest current setting (in electric arc) consistent with correct penetration and fusion of weld and parent metal.
(2) Line up the work to ensure correct alignment on cooling out of the weld.
(3) Use step-back or skip method of welding.
(4) Use wedges or clamps.

Methods of reducing or relieving stress

(1) Weld from fixed end to free end.
(2) Peening.
(3) Heat treatment.

Finally, the following is a summary of the chief factors responsible for setting up residual stresses:

(1) Heat present in the welds depending on:
    (*a*) Flame size and speed in oxy-acetylene welding.
    (*b*) Current and electrode size and speed in arc welding.
(2) Qualities of the parent metal and filler rod or electrode.
(3) Shape and size of weld.
(4) Comparative weight of weld metal and parent metal.
(5) Type of joint and method used in making weld (tacking, back stepping, etc.).
(6) Type of structure and neighbouring joints.
(7) Expansion and contraction (whether free to expand and contract or controlled).
(8) Rate of cooling.
(9) Stresses already present in the parent metal.

Brittle fracture

When a tensile test is performed on a specimen of mild steel it elongates first elastically and then plastically until fracture occurs at the waist which forms. We have had warning of the final failure because the specimen has elongated considerably before it occurs and has behaved both elastically and plastically. It is possible however, under certain conditions,

for mild steel (and certain alloy steels) to behave in a completely brittle manner and for fracture to occur without any previous elongation or deformation even when the applied stress is quite low, the loading being well below the elastic limit of the steel.

This type of fracture which takes place without any warning is termed brittle fracture and although it has been known to engineers for many years it was the failure of so many of the all-welded Liberty ships in World War II that focused attention upon it and brought welding as a method of construction into question.

It is not, however, a phenomenon which occurs only in welded fabrications because it has been observed in riveted constructions; but because welded plates are continuous as opposed to the discontinuity of riveted ones a brittle fracture in a welded fabrication may travel throughout the fabrication with disastrous results, whereas in a riveted fabrication it usually travels only to the edge of the plate in which it commenced.

From investigations into the problems which have been made both in the laboratory and on fractures which have occurred during service, it is apparent that certain significant factors contribute to the occurrence of brittle fracture and we may summarize these as follows:

(1) The ambient temperature when failure occurred was generally low, that is, near or below freezing point.
(2) Failure occurred in many cases when the loading on the areas was light.
(3) Failure is generally associated with mild steel but occurs sometimes in alloy steels.
(4) The fracture generally begins at defects such as artificial notches caused by sharp corners, cracks at a rivet hole, a fillet weld corner, poor weld penetration, etc., all behaving generally as a notch.
(5) The age of the structure does not appear to be a significant factor.
(6) Residual stresses may, together with other factors, serve to initiate the fracture.

Once the crack is started it may be propagated as a brittle fracture and can continue at high speeds up to 1200 m per second and at very low loads. It is a trans-granular phenomenon and after failure, tensile tests on other parts of the specimen will show a normal degree of ductility.

We may now consider briefly the conditions which may lead up to the occurrence of brittle fracture.

Notch brittleness

When stress is applied to a bar it may either deform plastically or may break in a brittle manner and the relationship between these types of behaviour determines whether brittle fracture will occur or not.

Consider a specimen of steel in which there is a notch and which is under a tensile stress. The stress on the specimen is below the elastic limit of the main section while at the root of the notch plastic flow may have occurred under a higher stress due to the reduced area.

This localized plastic flow at the notch may cause rapid strain hardening, which may lead to cracking at the root of the notch, and once this crack has begun we have a natural notch of uniform size instead of a variable-size machined notch. Before a crack can be initiated there must therefore be some deformation.

Ductile–brittle transition

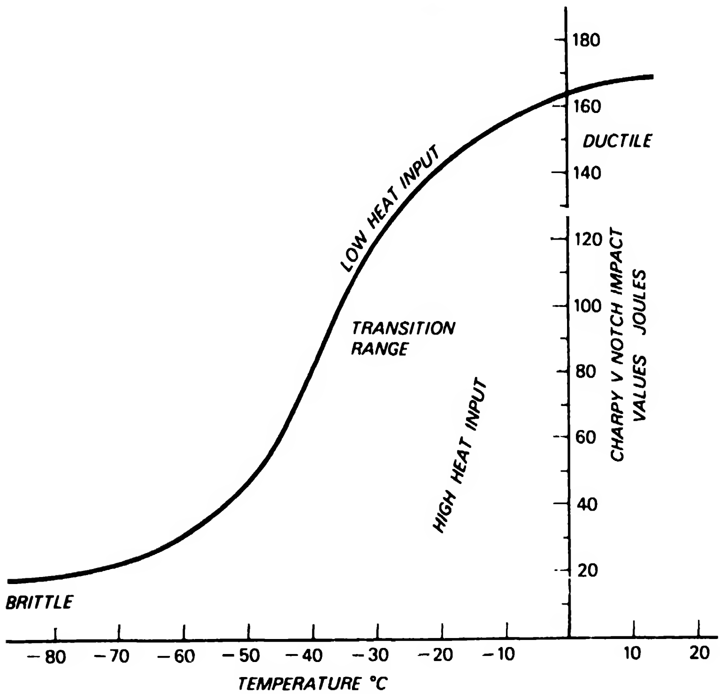
The transition from the ductile to the brittle state is affected by temperature, strain rate and the occurrence of notches.

If tests are performed on steel specimens at various temperatures it is found that the yield point stress increases greatly as the temperature is reduced so that the lower the temperature, the greater the brittleness and the liability to brittle fracture. The strain rate has a similar effect on the yield point. As the rate of strain is increased the yield stress rises much more quickly than the fracture stress. A notch may thus localize the stress to increase the strain at its root. The size of the ferrite grains also affects the transition temperature and increasing the carbon content raises and broadens the transition range. In the case of alloy steels, manganese and nickel lower the transition temperature while carbon, silicon and phosphorus raise it. By keeping a high manganese–carbon ratio, tendency to brittle fracture can be reduced and in general the lowest transition temperatures are obtained with finely dispersed microstructures. We may sum up the preceding by saying that the ductile–brittle transition of steel is affected by both grain size and microstructure, and in general the weld metal has similar or even better transition properties than the parent plate. Because of this, brittle fracture is seldom initiated in the weld metal itself but rather in the fusion zone, the heat-affected zone or the parent plate, and the fracture seldom follows the weld Faults in a weld such as slag inclusion, porosity, lack of fusion, and undercut, which occur in the fusion zone. may serve as nuclei for a crack from which the brittle fracture may be projected, and since the notch ductility of the weld is usually better than that of the plate the fracture follows the plate.

The notch ductility of a weld can be measured by means of the Charpy notch test (p. 286) and gives an indication of the resistance to brittle fracture. The impact values in joules are plotted against the temperature, first for a weld with a low heat input and then with a high heat input, and two curves are obtained as in Fig. 2.41, which are for a carbon–manganese

weld metal. It can be seen that the lower heat input gives higher impact values, but there is a transition range from ductile to brittle fracture, and as the temperature falls the probability of brittle fracture is greatly increased. The value of 41 J is often taken as the minimum for the weld metal since above this value it is considered that any crack which develops during service would be arrested before it could result in massive brittle fracture. To obtain good low-temperature impact values, low heat input is therefore required, which means that electrodes should be of the basic type and of small diameter, laid down with stringer bead (split weave) technique. Rutile-coated electrodes can be used down to about −10 C. Basic mild steel electrodes can be used down to about −50 C, and below that nickel-containing, basic-coated electrodes should be used.

Fig 2 41. Ductile brittle transition in a steel weld metal



3

*Metallic alloys and equilibrium diagrams**

Metallic alloys

The metals with which a welder may have to deal are often not pure metals but alloys consisting of a parent metal with one or more alloying elements added in various proportions, e.g. mild steel is an alloy mainly of iron with a small amount of carbon, while brasses are alloys of copper containing up to 45% of zinc.

The properties of such alloys vary according to the form in which the alloying element is present. There are several possible forms:

(1) The alloying element may be present in an unchanged form in a state of fine mechanical mixture with the parent metal so that it can be seen as a separate particle or crystal (constituent) under the microscope.

Examples of this are:

(*a*) Carbon present as flakes of graphite in grey cast irons.

(*b*) Silicon present as fine silicon crystals in the aluminium–silicon alloys.

(*c*) Lead present as round particles in free cutting brasses. Alloying elements present in this condition do not generally produce a great increase in strength, but they increase or decrease the hardness, reduce the ductility and improve the machinability of the parent metal.

(2) The alloying element may be present in solid solution in the parent metal, i.e., actually dissolved as salt or sugar dissolves in water, so that under the microscope only one constituent, the solid solution, can be seen, similar in appearance to the parent metal except that the colour may be changed.

* This chapter will give the welding engineer an introduction to equilibrium diagrams and their uses.

Examples of this are:

(*a*) Up to 37% of zinc can be present in solid solution in copper, causing its colour to change gradually from red to yellow as the percentage of zinc increases. These alloys are known as alpha brasses.

(*b*) Up to about 8% of tin or aluminium can be present in solid solution in copper giving alloys known as alpha tin bronzes or alpha aluminium bronzes respectively.

(*c*) Copper and nickel in any proportion form a solid solution of the same type. Examples are cupro-nickel containing 20–30% nickel and Monel metal containing about 70% nickel. All have a similar appearance under the microscope showing a simple structure similar to that of a pure metal.

Elements in solid solution improve strength and hardness without making the metal brittle.

(3) The alloying element may form a compound with the parent metal which will then have properties different from either. Such compounds are generally hard and brittle and can only be present in small amounts and finely distributed without seriously impairing the properties of the alloy.

These appear under the microscope as distinct new constituents often of clearly crystalline shape. A second type of inter-metallic compound (a new constituent) having ductility and properties more like a solid solution forms in some alloys at certain ranges of composition. An example is the β constituent in brasses containing 40–50% zinc.

(4) While some pairs of metals are soluble in each other in all proportions, e.g. copper and nickel, other pairs can only retain a few per cent of each other in solid solution. If one of the alloying elements is present in a greater amount than the maximum which can be retained in solid solution in the parent metal, then part of it will be in solid solution and part will be present as a second constituent, i.e., either:

(*a*) as crystals of the alloying element which may themselves have a small amount of the parent metal in solid solution, or

(*b*) as an inter-metallic compound.

The state in which an alloying element is present can vary with the temperature so that the constituents present in an alloy at ordinary temperatures may be different from those present at the temperature of the welding operation. For all alloys used in practice, however, the constituents present at any temperature, from that of the welding range down to that of the room, have been determined by quenching the alloys from the various temperatures and examining them under the microscope. Each constituent which can be recognized as separable distinct particles or crystals is called a

phase, and an alloy is said to be single-phase, two-phase or three-phase, etc., according to the number of phases present.

For any pair of metals, the different combinations of phases which may be produced by varying either the composition of the alloy, or the temperature, can be shown in an *equilibrium* or constitutional diagram for that pair of metals. In these diagrams composition is plotted horizontally and temperature vertically. The diagram is subdivided into a number of areas called phase-fields each of which is labelled with the phase or phases which occur within its limits. On the diagram are also plotted curves showing how the melting point and freezing point change with the composition.

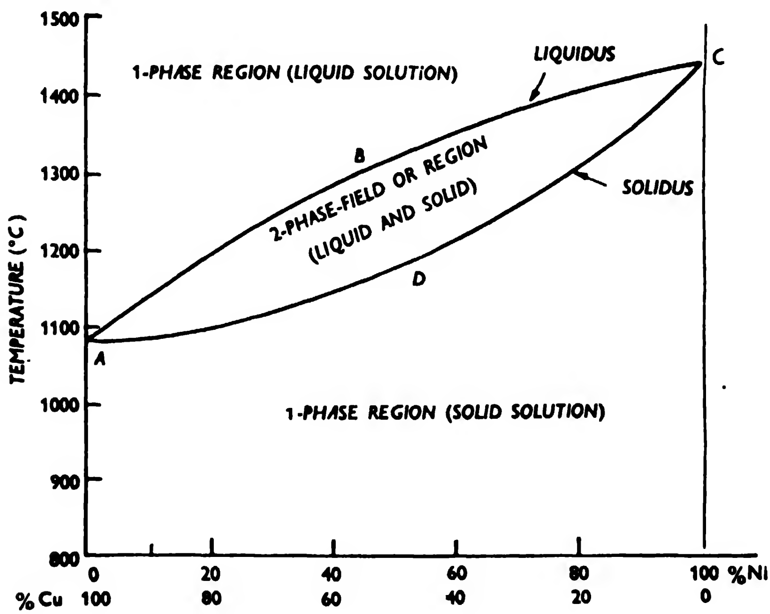
Thus a glance at the diagram will show for any composition, the phases present at any chosen temperature. Furthermore the diagram shows what changes will occur in any composition if it is cooled slowly from, say, the welding temperature to normal air temperature.

Equilibrium diagrams and their uses

Two metals soluble in each other in all proportions

In Fig. 3.1 *A* is the melting point of pure copper and *C* that of pure nickel. The percentage composition (Cu and Ni) is plotted horizontally and the temperature vertically.

Fig. 3.1



Above the curve *ABC*, which is called the liquidus, any mixture of copper and nickel will be a single liquid solution. This region is called a single-phase field. Below the curve *ADC*, called the solidus, any mixture of copper and nickel will consist of a single solid solution and under the microscope will show no difference between one composition and another except for a gradual change in colour from the red colour of copper to the white of nickel as the percentage of nickel is increased. The region below the curve *ADC* is therefore a single-phase field.

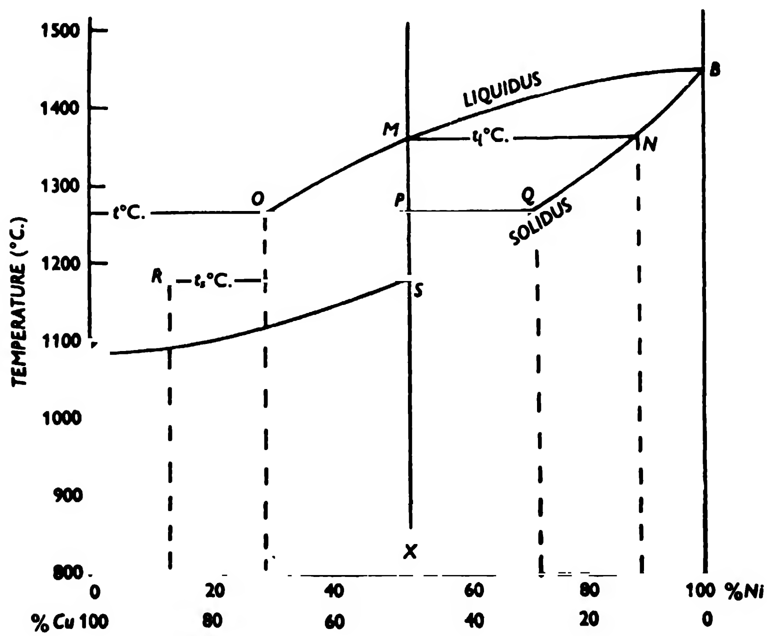
In the region between the curves *ABC*, *ADC* any alloy contains a mixture of:

(1) solid solution crystals, and
(2) liquid solution.

This region is therefore a two-phase field. There is a simple rule for determining the compositions and proportions of the liquid and solid solutions which are present together at any selected temperature in a two-phase field. Let *X* be the composition of any selected alloy (Fig. 3.2) and let $t°$ be selected temperature.

Draw a horizontal line at temperature $t°$ to cut the liquidus at *O* and the solidus at *Q*. Then *O* is the composition of the liquid solution (say approx. 28% Ni, 72% Cu) and *Q* the composition of the solid solution (say 73% Ni, 27% Cu) present in the alloy *X* at temperature $t°$. The relative amounts of liquid *O* and the solid *P* are given by the lengths of *PQ* and *OP* respectively.

Fig 3.2



When the alloy of composition X cools from the liquid condition to normal temperatures, the changes involved may be summarized as follows. No change occurs until the alloy cools to the liquidus temperature t_l°. When t_l° is reached a small amount of solid solution of composition N (say 90% Ni, 10% Cu) is formed. On further cooling these crystals absorb more copper from the liquid and more crystals separate out but their composition changes progressively along the solidus line towards S getting richer in copper, while the composition of the remaining liquid changes progressively along the liquidus line towards composition R. The amount of solid present therefore increases and the amount of liquid decreases until when the temperature t_s° is reached (this is the solidus temperature of our alloy of composition X) the last drop of liquid solidifies and the whole alloy is then a uniform solid solution of composition X. No further changes occur on cooling to normal temperatures, and under the microscope the cooled alloy will appear to consist of polygonal grains of one kind only, differing from a pure metal only in the colour.

This simplified description applies only when the alloy solidifies very slowly, for time is required for the first crystals deposited (composition N) to absorb copper by diffusion so that they change progressively along NS as solidification occurs. When cooling is rapid there is not sufficient time for these changes to occur in the solidified crystals and we get the first part of each crystal having composition N, so that the centre of each crystal or grain is richer in nickel than the average, while as we progress from the centre to the outside the composition gradually changes, becoming richer in copper until at the boundaries of each grain they are richer in copper than the average composition X. This effect is known as *coring* and is shown as a gradual change in colour of the crystals when the alloy is etched with a suitable chemical solution and examined under the microscope. All solid solution alloys show coring to a greater or lesser degree when they are solidified at normal rates, for example in a casting or welding operation.

Coring can be removed and the composition of each grain made uniform throughout by re-heating or annealing at a temperature just below the solidus of the alloy.

Two metals partially soluble in each other in the solid state, which do not form compounds

This type of alloy system is very common, e.g. copper–silver, lead–tin, aluminium–silicon. It is called a *eutectic system* and at the eutectic composition, that is, at the minimum point on the liquidus curve, the alloy solidifies at a constant temperature instead of over a range of temperatures.

In the solid state there are three phase-fields (Fig. 3.3):

(1) A single-phase region in which any composition consists of a solid solution of metal *B* in metal *A* (α only).

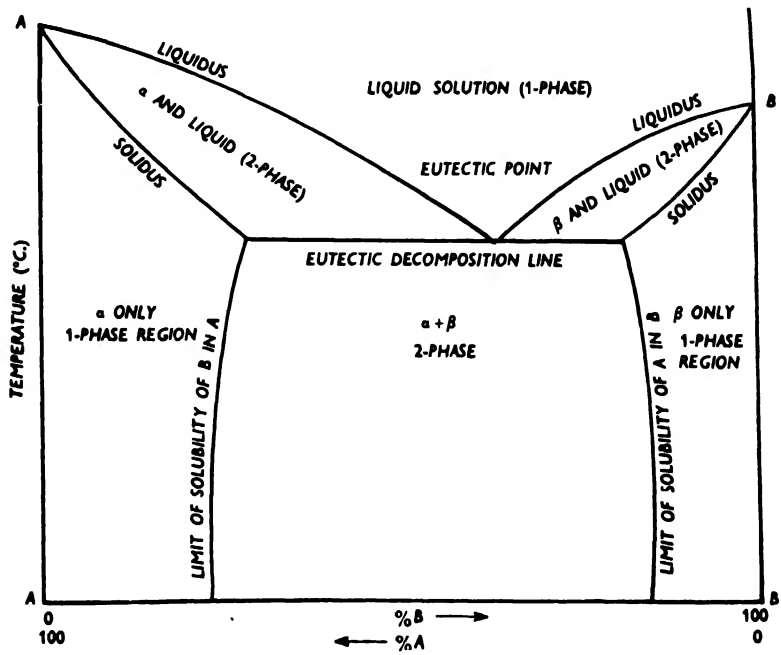
(2) A single-phase region in which any composition consists of a solid solution of metal *A* in metal *B* (β only).

(3) A two-phase region in which any alloy consists of a mechanical mixture of the two solid solutions mentioned above ($\alpha + \beta$).

Solidification of alloys forming a eutectic system. (1) Alloys containing less than $X\%$ or more than $Z\%$ of metal *B* will solidify as solid solutions similar to those of the copper–nickel system. In Fig. 3.4 consider an alloy of composition at (1). As it cools, crystals of composition S_1 will begin to separate out at L_1. On further cooling the liquid will change in composition along the liquidus to L_2 and the solid deposited will change along the solidus to S_2. At S_2 the last drop of liquid will solidify and if cooling has been slow, the grains will be a uniform solid solution of composition (1); with rapid cooling the crystal grains will be cored, the centres richer in metal *A* and the boundaries richer in metal *B*.

(2) The eutectic alloy will cool as a liquid solution to *Y*. At *Y*, crystals of two solid solutions will separate simultaneously, their compositions being

Fig. 3.3



given by the points Z and X. Solidification will be completed at constant temperature and the solidified alloy will consist of a fine mechanical mixture of the two solid solutions, called a eutectic structure.

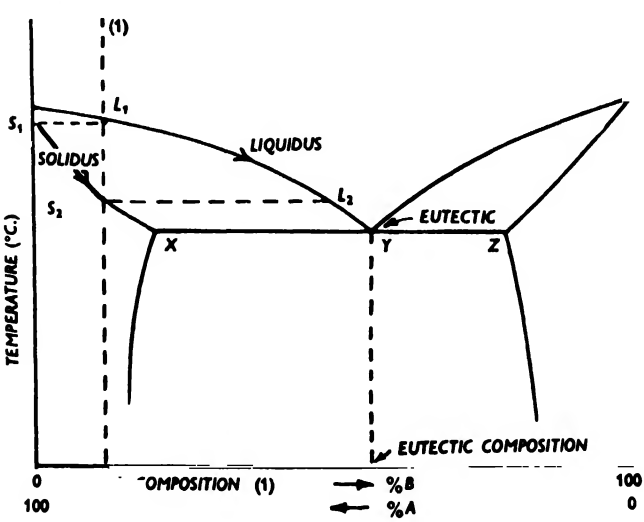
(3) An alloy of composition between X and Y, or between Y and Z, will begin to solidify as a solid solution but when the composition of the liquid has reached the point Y, the remainder will solidify as a fine eutectic mixture of X and Z.

Two metals which form intermetallic compounds

Compound forming a eutectic system with the parent metal. The equilibrium diagram for many alloying elements which form compounds with the parent metal, e.g. copper alloyed to aluminium, is of a simple eutectic form similar to that just considered for the important part of the diagram, and the changes occurring on cooling an alloy of such a system are similar to those given in (2) above. (In Fig. 3.5, which is for Al–Cu alloy, the intermetallic compound θ formed is $CuAl_2$.)

System in which an intermetallic compound is formed by a reaction. In some alloy systems, notably those in which copper is the parent metal, an intermediate phase or inter-metallic compound is formed as a product of a reaction which occurs in certain compositions during solidification. An example is that of the copper–zinc system in which a β phase is formed by a peritectic reaction.

Fig. 3 4



Solidification of alloys in a peritectic system. Referring to Fig. 3.6, alloys containing less than 32.5% of zinc at *A*, solidify as α solid solutions by the process described for class (1). Alloys containing between 32.5% and 39% zinc (*A* and *C* in the figure) commence to solidify by forming crystals of the α solid solution, but when the temperature has fallen to 905 °C, the liquid is of composition at *C* (39% Zn) and the α crystals are of composition at *A*

Fig. 3.5

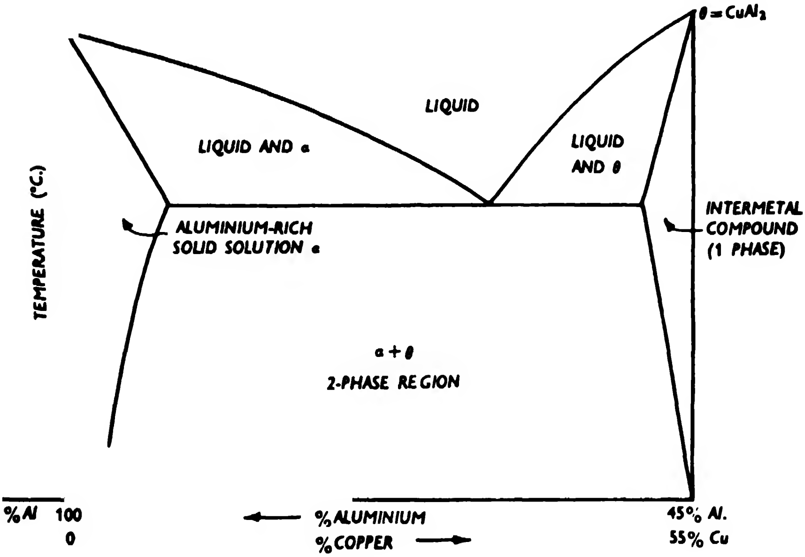
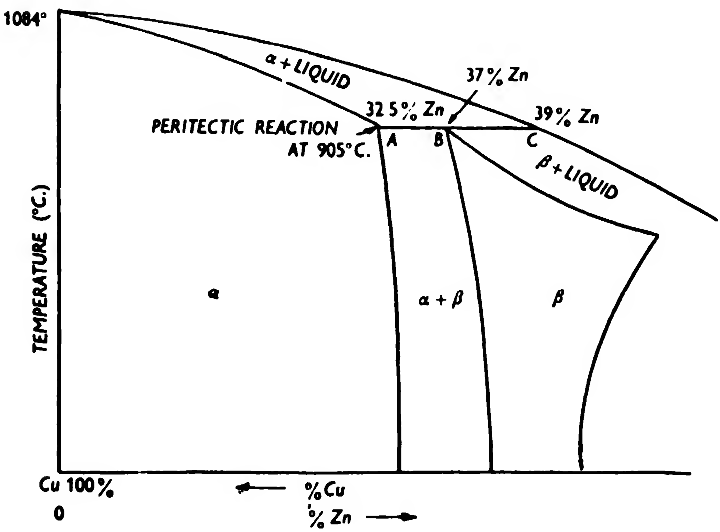


Fig 3.6



(32.5% Zn). At this temperature the α phase and the liquid react to form a new solution β having a composition at B(37% Zn). This reaction is termed a *peritectic reaction.*

If the mean composition of the alloy is B% zinc (37%) then all the liquid and the α crystals are converted to β solution and at the end of solidification the alloy is a uniform solid solution β.

If the alloy contains between A% and B% of zinc, the alloy after solidification consists of a mixture of α and β. If the alloy contains between B% and C% of zinc, all the α crystals are converted to β at the peritectic reaction, but there is some liquid left which then solidifies as β by the usual mechanism of solidification for a solid solution.

Phase changes in alloys in the solid state

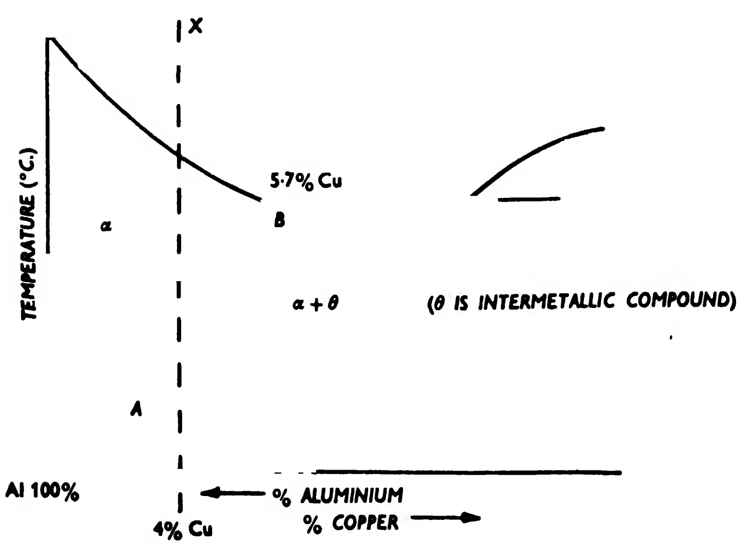
There are two important types of phase change which may occur in alloys while cooling in the *solid* state.

Simple solubility change. In many alloy systems the amount of the alloying element which can be kept in solid solution in the parent metal decreases as the temperature falls.

This effect is shown in the equilibrium diagram Fig. 3.7 by the slope of the solubility line, that is, the line which marks the limit of the single-phase region of the α solid solution.

Thus in the copper–aluminium system, aluminium will dissolve 5.7% of

Fig. 3.7



copper at the eutectic temperature but the solubility falls to less than 0.5% copper at ordinary temperatures.

The alloys containing up to 5.7% copper are α solid solutions at temperatures above the line *AB*, but below the line *AB* they consist of α solid solutions with varying amounts of an inter-metallic compound θ.

If the alloy of composition *X* (say 4% copper) is annealed above the line *AB*, say at 530 °C and quenched in water, a super-saturated solid solution is obtained. If, on the other hand, it is cooled slowly, on reaching the line *AB* crystals of the inter-metallic compound θ begin to separate out (or are precipitated) and increase in size and number on further cooling.

If a quenched specimen is retained at room temperature, the excess copper in solution tends to diffuse out to form separate θ crystals and this process produces severe hardening of the alloy known as *age hardening*. No visible change in the microstructure occurs.

If a quenched specimen is heated to 100–200 °C the diffusion and hardening occur more quickly. This is known as *temper hardening*, but if the heating is too prolonged, visible crystals of θ separate out and the alloy resoftens. This is known as *over-ageing*.

Eutectoid change. In steels the remarkable changes in properties which can be obtained by different types of heat treatment are the result of a different type of transformation in the solid state. This is known as a *eutectoid transformation*.

Some solid solutions can only exist at high temperatures and on cooling they decompose to form a fine mixture of two other phases. This change, known as a *eutectoid* decomposition, is similar to a eutectic decomposition (see p. 157) except that the solution which decomposes is a solid one instead of a liquid one. The structure produced is also similar in appearance under a microscope to a eutectic structure but is in general finer.

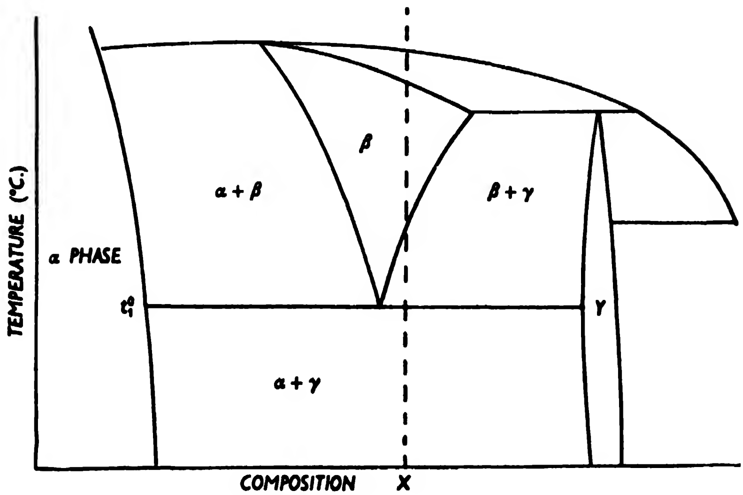
In Fig. 3.8 the β phase undergoes eutectoid decomposition at temperature t_1° to form a eutectoid mixture of α phase $+\gamma$ phase.

If an alloy, which contains some β phase at high temperatures, say composition *X* in the figure, is quenched from a temperature higher than t_1, the decomposition of β is prevented and severe hardening is produced. If the alloy *X* is now heated to some temperature below t_1 the change of β to $\alpha + \gamma$ can occur and the hardening is removed. This is then a tempering process.

In some systems in which a change of this type occurs it is possible to obtain a wide range of hardness values in a single alloy according to the rate of cooling from above the decomposition temperature. The *slower* the cooling rate the coarser is the ($\alpha + \gamma$) eutectoid mixture and the lower the

hardness, and vice versa, the quench giving the highest hardness obtainable.

Fig. 3.8



4

Basic electrical principles

Electrical technology

Sources of electrical power

The principle sources of electrical power of interest to the welder are (1) batteries and accumulators, (2) generators.

Batteries generate electrical energy by chemical action. Primary batteries, such as the Leclanché (used for flash lamps and transistor radios), continue giving out an electric current until the chemicals in them have undergone a change, and then no further current can be given out.

Secondary batteries or accumulators are of two types: (1) the lead–acid, and (2) the nickel–iron alkaline. In the former, for example, there are two sets of plates, one set of lead peroxide and the other set of lead, immersed in dilute sulphuric acid (specific gravity 1.250, i.e. 4 parts of distilled water to 1 part of sulphuric acid). Chemical action enables this combination to supply an electric current, and when a current flows from the battery both the lead peroxide plates and the lead plates are changed into lead sulphate, and when this change is complete the battery can give out no more current. By connecting the battery to a source of electric power, however, and passing a current through the battery in the opposite direction from that in which the cell gives out a current, the lead sulphate is changed back to lead peroxide on one set of plates and to lead on the other set. The battery is then said to be 'charged' and is ready to supply current once again.

It may also be noted here that when two different metals are connected together and a conducting liquid such as a weak acid is present, current will flow, since this is now a small primary cell. This effect is called 'electrolysis' and will lead to corrosion at the junction of the metals.

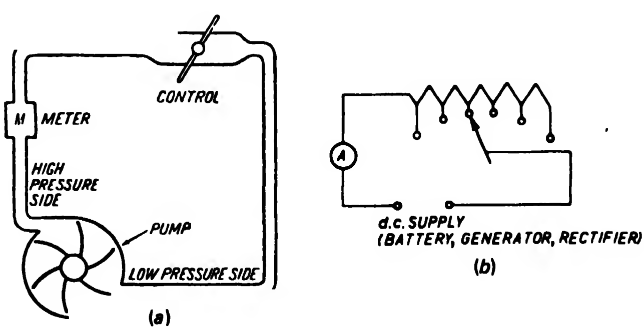
Generators can be made to supply direct current or alternating current as required and are described later. For welding purposes generators of special design are necessary. When welding with alternating current,

'transformers' are used to transform or change the pressure of the supply to a pressure suitable for welding purposes.

The electric circuit

The electric circuit can most easily be understood by comparing it to a water circuit. Such a water circuit is shown in Fig. 4.1*a*. A pump drives or forces the water from the high-pressure side of the pump through pipes to a water meter *M*, which measures the flow of water in litres per hour. From the meter the water flows to a control valve, the opening in which can be varied, thus regulating the flow of water in the circuit. The water is led back through pipes to the low-pressure side of the pump. We assume that no water is lost in the circuit. Fig. 4.1*b* shows an electric circuit corresponding to this water circuit. The generator, which supplies direct current (d.c.), that is, current flowing in one direction only, requires energy to be consumed in driving it. The electrical pressure available at the terminals of the generator when no current is flowing in the circuit is known as the electro-motive force (e.m.f.) or in welding as the open circuit voltage. The current is carried by copper wires or cables, which offer very little obstruction or resistance to the flow of current through them, and the current flows from the high-pressure side of the generator (called the positive or +ve pole) through a meter which corresponds to the water meter. This meter, known as an ampere meter or ammeter, measures the flow of current through it in amperes, A (amps for short), just as the water meter measures the flow of water in litres per hour. This ammeter may be connected at any point in the circuit so that the current flows *through* it, since the current is the same at all points in the circuit. From the ammeter the current flows through a copper wire to a piece of apparatus called a 'resistor'. This consists of wire usually made of an alloy, such as manganin,

Fig. 4.1



nichrome or eureka, which offers considerable obstruction or resistance to the passage of a current.

The number of turns of this coil in the circuit can be varied by means of a switch, as shown in the figure. This resistor corresponds to the water valve by which the flow of water in the circuit is varied. The more resistance wire which we include in the circuit, the greater is the obstruction to the flow of the current and the less will be the current which will flow, so that as we increase the number of turns or length of resistance wire in the circuit, the reading of the ammeter, indicating the flow of current in the circuit, becomes less. The current finally flows through a further length of copper wire to the low-pressure (negative or −ve) side of the generator.

In the water circuit we can measure the pressure of water in N/mm^2 by means of a pressure gauge. We measure the difference of pressure or potential (p.d.) between any two points in an electric circuit by means of a voltmeter, which indicates the difference of pressure between the two points in volts. Fig. 4.2 shows the method of connexion of an ammeter and a voltmeter in a circuit.

Fall in potential – voltage drop. Let us consider the circuit in Fig. 4.3 in which three coils of resistance wire are connected to each other and to the generator by copper wires as shown, so that the current will flow through each coil in turn. (This is termed connecting them in *series*.) Suppose that the current flows from the + ve terminal A through the coils and back to the − ve terminal H. Throughout the circuit from A to H there will be a gradual fall in pressure or potential from the high-pressure side A to the low-pressure side H. Let us place a voltmeter across each section of the circuit in

Fig. 4.2

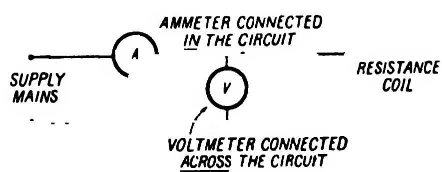
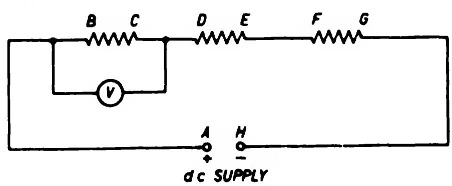


Fig. 4.3



turn and find out where this fall in pressure or *voltage drop* occurs. If the voltmeter is first placed across *A* and *B*, we find that no difference of pressure or voltage drop is registered. This is because the copper wire connecting *A* and *B* offers very little obstruction indeed to the passage of the current, and hence, since there is no resistance to be overcome, there is no drop in pressure.

If the voltmeter is placed across *B* and *C*, however, we find that it will register a definite amount. This is the amount by which the pressure has dropped in forcing the current against the obstruction or resistance of *BC*. Similarly, by connecting the meter across *DE* and *FG* we find that a voltage drop is indicated in each case, whereas if connected across *CD*, *EF*, or *GH*, practically no drop will be recorded, because of the low resistance of the copper wires.

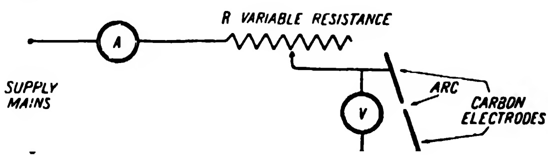
If we add up the voltage drops across *BC*, *DE* and *FG*, we find that it is the same as the reading that will be obtained by placing the voltmeter across *A* and *H*, that is, the sum of the voltage drops in various parts of a circuit equals the pressure applied.

The question of voltage drop in various parts of an electric circuit is important in welding. Fig. 4.4 shows a circuit composed of an ammeter, a resistance coil, and two pieces of carbon rod called electrodes. This circuit is connected to a generator or large supply battery, as shown. When the carbons are touched together, the circuit is completed and a current flows and is indicated on the ammeter. The amount of current flowing will evidently depend on the amount of resistance in the circuit.

If now the carbons are drawn apart about 4 mm, the current still flows across the gap between the carbons in the form of an arc. This is the 'carbon arc', as it is termed. We can control the current flowing across the arc by varying the amount of resistance *R* in the circuit, while if a voltmeter is placed across the arc, as shown, it will register the drop in pressure which occurs, due to the current having to be forced across the resistance of the gap between the electrodes. We also notice that the greater the distance between the electrodes the greater the voltage drop. The metallic arc used in arc welding is very similar to the carbon arc and is discussed fully later.

It has been mentioned that copper wire offers little obstruction or

Fig 4.4



resistance to the passage of a current. All substances offer some resistance to the passage of a current, but some offer more than others. Metals, such as silver, copper and aluminium, offer but little resistance, and when in the form of a bar or wire the resistance that they offer increases with the length of the wire and decreases with the area of cross-section of the wire. Therefore the greater the length of a wire or cable, the greater its resistance; and the smaller the cross-sectional area, the greater its resistance. Thus if we require to keep the voltage drop in a cable down to the lowest value possible as we do in welding, the longer that the cable is, the greater must we make its cross-sectional area. Unfortunately, increasing the cross-sectional area makes the cable much more expensive and increases its weight, so evidently there is a limit to the size of cable which can be economically used for a given purpose.

Series and parallel groupings. We have seen that if resistors are connected together so that the current will flow through each one in turn, they are said to be connected in series (Fig. 4.5*a*). If they are connected so that the current has an alternative path through them, they are said to be connected in parallel or shunt (Fig. 4.5*b*).

An example of the use of a parallel circuit is that of a shunt for an ammeter. The coil in an ammeter has a low resistance and will pass only a small current so that when large currents as used in welding are involved, it is usual to place the ammeter in parallel or shunt with a resistor (termed the ammeter shunt) which is arranged to have a resistance of such value that it carries the bulk of the current, for example 999/1000 of the total current. In this case, if the welding current were 100 A, 99.9 A would pass through the shunt and 0.1 A through the instrument coil, but the ammeter is calibrated with the particular shunt used and would read 100 A (Fig. 4.6*a*).

Fig. 4.5

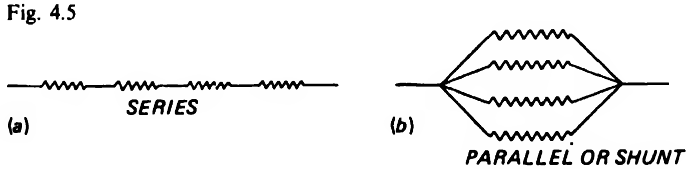
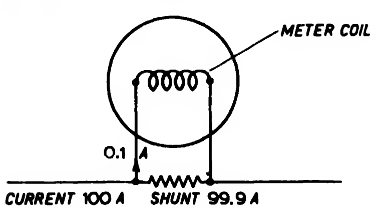


Fig. 4.6. (*a*) Ammeter shunt.



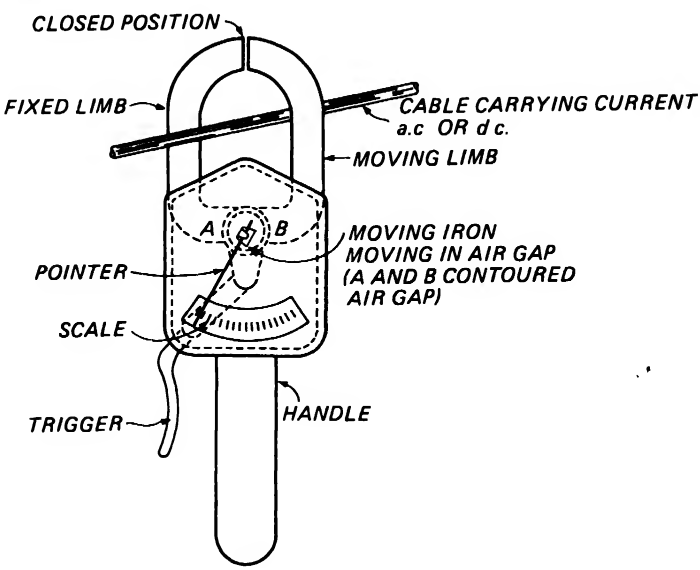
Link testing ammeter. This useful instrument (Fig. 4.6*b*) enables the current, in either a d.c. or an a.c. circuit, to be measured without breaking the electrical circuit. It is a fluxmeter with pole pieces or links, one of which is fixed and the other moving on a hinge and operated by a trigger on the instrument handle which enables the pole pieces to encircle the circuit with the current to be measured. The indicating meter, calibrated in amperes, is a spring controlled moving iron type in a moulded insulated case. This meter is available in various current ranges, e.g. 0–50 amps to 0–800 amps, and can be plugged into the instrument body thus increasing its usefulness.

Conductors, insulators and semi-conductors

Substances may be divided into two classes from an electrical point of view: (1) conductors, (2) insulators.

Conductors. These may be further divided into (*a*) good conductors, such as silver, copper and aluminium, which offer very little obstruction to the passage of a current, and (*b*) poor conductors or resistors, which offer quite a considerable obstruction to the passage of a current, the actual amount depending on the particular substance. Iron, for example, offers six times as much obstruction to the passage of a current as copper and is said to have six times the resistance. Alloys, such as manganin, eureka, constantin,

Fig. 4.6 (*b*)



german silver, no-mag and nichrome, etc., offer much greater obstruction than iron and have been developed for this purpose, being used to control the current in an electric circuit. No-mag, for example, is used for making resistance banks for controlling the current in motor and arc welding circuits, etc., while nichrome is familiar, since it is used as the heating element in electric fires and heating appliances, the resistance offered by it being sufficient to render it red hot when a current flows. Certain rare metals, such as tantalum, osmium and tungsten, offer extremely high obstruction, and if a current passes through even a short length of them in the form of wire they are rendered white hot. These metals are used as filaments in electric-light bulbs, being contained in a bulb exhausted of air, so as to prevent them oxidizing and burning away.

Insulators. Many substances offer such a great obstruction to the passage of a current that no current can pass even when high pressures are applied. These substances are called insulators, but it should be remembered that there is no such thing as a perfect insulator, since all substances will allow a current to pass if a sufficiently high pressure is applied. In welding, however, we are concerned with low voltages. Amongst the best and most familiar insulators are glass, porcelain, rubber, shellac, mica, oiled silk, empire cloth, oils, resins, bitumen, paper, etc. In addition, there is a series of compounds termed synthetic resins (made from phenol and formalin), of which 'bakelite' is a well-known example. These compounds are easily moulded into any desired shape and have excellent insulating properties. Plastics such as polyvinyl chloride (PVC) and chloro-sulphonated-polyethylene (CSP) are now used for cable insulation in place of rubber. PVC is resistant to oil and grease and if ignited does not cause flame spreading. At temperatures near freezing it becomes stiff and more brittle and is liable to crack, while at high temperature it becomes soft. As a result PVC insulation should not be used where it is near a heat source such as an electric fire or soldering iron.

The insulating properties of a substance are greatly dependent on the presence of any moisture (since water will conduct a current at fairly low pressures) and the pressure or voltage applied. If a person is standing on dry boards and touches the + ve terminal of a supply of about 200 volts, the − ve of which is earthed, very little effect is felt. If, however, he is standing on a wet floor, the insulation of his body from the Earth is very much reduced and a severe shock will be felt, due to the much larger current which now passes through his body. As the voltage across an insulator is increased, it is put in a greater state of strain to prevent the current passing, and the danger of breakdown increases.

All electrical apparatus should be kept as dry as possible at all times. Much damage may result from wet or dampness in electrical machines.

Semi-conductors. Most materials are either conductors or insulators of an electric current, but a small group termed semi-conductors fall in between the above types. To compare the resistance of various substances a cube of 1 metre edge is taken as the standard and the resistance between any pair of opposite faces of this cube is termed the resistivity, and is measured in ohm-metre.

Conductors have a low resistivity, copper, for example, being about 1.7×10^{-8} ohm-metre. Insulators have a high resistivity varying between 10^{10} and 10^{18} ohm-metre. Silicon and germanium are semi-conductors and their resistivity depends upon their purity. If a crystal of silicon has a very small amount of antimony or indium added as an impurity its resistivity is lowered, and the greater the amount of impurity the lower the resistivity. If a small amount of antimony is added to one half of a silicon crystal and a small amount of indium to the other half, the junction between these types (termed *n* type and *p* type) acts as a barrier layer, so that the crystal acts as a conductor in one direction and offers a high resistance in the other, in other words it can act as a rectifier. This is the principle of the solid state silicon diode (because it has two elements or connexions) used as a rectifier for d.c. welding supplies.

Superconductors. At the temperature of liquid helium (BP 4.2 K) certain materials lose their electrical resistance so that any current flowing in them has no heating effect and thus there is no loss of power. The temperature at which this change to superconduction takes place is termed the transition temperature. The relatively high cost of the liquid helium required to obtain the very low transition temperature in the above example has restricted the use of this superconductor. Research has now produced a mixture of ceramic oxides which exhibits superconducting properties at higher transition temperatures, nearer to that of liquid nitrogen (77 K), which is more plentiful and cheaper. The material is made by grinding chosen oxides together and then heating the mixture for several hours at an elevated temperature. The ceramic produced is then cooled and ground and often annealed, the result being the superconductor.

More research into superconductors made of various rare earth materials may eventually raise the transition temperature to that of the room, greatly extending their use in medicine, computers, VDUs etc.

Welding cables

A cable to conduct an electric current consists of an inner core of copper or aluminium covered with an insulating sheath. Welding cables have to carry quite large currents and must be very flexible and as light as possible, and to give this flexibility the conductor has very many strands of small diameter. The conductor is covered by a thick sheath of tough rubber (TRS) or synthetic rubber (CSP) to give the necessary insulation at the relatively low voltages used in welding. As great flexibility is often not required in the return lead, a cable of the same sectional area but with fewer conductors of larger diameter can be used with a saving in cost.

CSP is a tough flexible synthetic rubber with very good resistance to heat, oils, acids, alkalis, etc., and is a flame retardant. It can be used at higher current densities than a TRS cable of the same sectional area, and its single-sheath construction gives good mechanical strength.

Copper is usually used as the conductor, but aluminium conductors are now used and are lighter than the same sectional area copper, are economical, less liable to pilfering but are larger in diameter and less flexible. In cases where considerable lengths of cable are involved a short length of copper conductor cable can be plugged in between the aluminium cable and electrode holder to give increased flexibility and less liability of conductor fracture at the holder.

Copper-clad aluminium conductors are available with 10% or 20% cladding, increasing the current-carrying capacity for a given cable size and reducing corrosion liability. Clamped or soldered joints can be used and in general TRS cables with copper conductors are probably the best and most economical choice in cases where high-current rating and resistance to corrosive conditions are not of prime importance.

In order to select the correct size of cable for a particular power unit it is customary to indicate for a given cable its current-carrying capacity in amperes (allowing for a permissible rise in temperature) and the voltage drop which will occur in 10 metres length when carrying a current of 100 A, as shown in the table. For greater lengths and currents the voltage drop increases proportionally.

Duty cycle. Cables for welding range from those on automatic machines in which the current is carried almost continuously, to very intermittent manual use in which the cable has time to cool in between load times. To obtain the current rating for intermittently loaded cables the term duty cycle is used. The duty cycle is the ratio of the time for which the cable is carrying the current to the total time, expressed as a percentage. If a cable is

used for 6 minutes followed by an off load period of 4 minutes the duty cycle is 6/10 × 100 = 60%. Average duty cycles for various processes are: automatic welding, up to 100%; semi-automatic, 30–85%; manual, 30–60%. Welding cables (BS 638) have many conductors of very small diameter to increase flexibility and may be divided into the following classes:

(1) Single core high conductivity tinned copper (HCC) conductors, paper taped and covered with tough rubber.
(2) Single core HC tinned copper conductors, paper taped and covered with chlorosulphonated polyethylene (CSP)
(3) Single core aluminium conductors (99.5% pure), paper taped and covered with CSP. The CSP cables have a 25% increase in sheath thickness without additional weight.

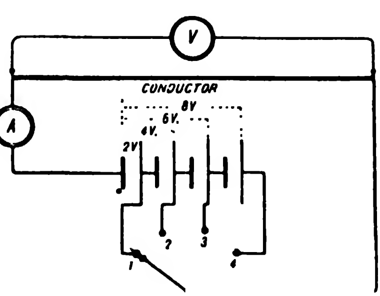
Ohm's law

Let us now arrange a conductor so that it can be connected to various pressures or voltages from a battery, say 2, 4, 6 and 8 volts, as shown in Fig. 4.7. A voltmeter V is connected so as to read the difference of

TRS and CSP insulated cables, copper conductors

Cross-sectional area of conductor in mm²	Number and diameter of wires. No./mm	Max overall diameter, mm	Current rating A max. duty cycle						d c volts drop 100 A/m of cable at	
			100%		60%		30%			
			CSP	TRS	CSP	TRS	CSP	TRS	20 °C	60 °C
16	513/0.20	11.5	135	105	175	135	245	190	1.19	1.38
25	783/0.20	13.0	180	135	230	175	330	245	0.78	0.90
35	1107/0.20	14.5	225	170	290	220	410	310	0.55	0.64
50	1566/0.20	17.0	285	220	370	285	520	400	0.39	0.45
70	2214/0.20	19.5	355	270	460	350	650	495	0.28	0.32
95	2997/0.20	22.0	430	330	560	425	790	600	0.20	0.24
120	608/0.50	24.0	500	380	650	490	910	690	0.16	0.18
185	925/0.50	29.0	660	500	850	650	1200	910	0.10	0.12

Fig. 4.7



pressures between the ends of the conductor, and an ammeter is connected so as to read the current flowing in the circuit. Connect the switch first to terminal 1 and read the voltage drop on the voltmeter and the current flowing on the ammeter, and suppose just for example that the readings are 2 volts and 1 ampere. Then place the switch on terminals 2, 3 and 4 in turn and read current and voltage and enter them in a table, as shown below. The last column in the table represents the ratio of the voltage applied to the current flowing, and it will be noted that the ratio is constant, that is, it is the same in each case, any small variations being due to experimental error.

In other words, when the voltage across the conductor was doubled, the current flowing was doubled; when the voltage was trebled, the current was trebled, and so on. This result led the scientist Ohm to formulate his law, thus: The ratio of the steady pressure (or voltage) across the ends of a conductor, to the steady current (or amperes) flowing in the conductor, is constant (provided the temperature remains steady throughout the experiment, and the conductor does not get hot. If it does, the results vary somewhat. Ohm called this constant the *resistance* of the conductor. In other words, the resistance of a conductor is the ratio of the pressure applied to its ends, to the current flowing in it.

Voltage or pressure drop	Current flowing (amperes)	Ratio: voltage/current
2	1	$\frac{2}{1} = 2$
4	2	$\frac{4}{2} = 2$
6	3	$\frac{6}{3} = 2$
8	4	$\frac{8}{4} = 2$

If now a difference of pressure of 1 volt applied to a conductor causes a current of 1 ampere to flow, the resistance of the conductor is said to be 1 ohm, that is, the ohm is the unit of resistance, just as the volt is the unit of pressure and the ampere the unit of current. That is

1 volt/1 ampere = ohm

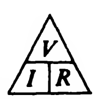
or, expressed in general terms,

voltage/current = resistance.

Another way of expressing this is

voltage drop = current × resistance.

A useful way of remembering this is to write down the letters thus:



(*V* being the voltage drop, *I* the current, and *R* the resistance). By placing the

finger over the unit required, its value in terms of the others is given. For example, if we require the resistance, place the finger over R and we find that it equals V/I, while if we require the voltage V, by placing the finger over V we have that it equals $I \times R$. The following typical examples show how Ohm's law is applied to some simple useful calculations.

Example

A pressure of 20 volts is applied across ends of a wire, and a current of 5 amperes flows through it. Find the resistance of the wire in ohms.

$$R = \frac{V}{I} = \frac{20}{5} = 4 \text{ ohms.}$$

Example

A welding resistor has a resistance of 0.1 ohm. Find the voltage drop across it when a current of 150 amperes is flowing through it.

$$V = I \times R, \quad \text{i.e.} \quad V = 150 \times 0.1 = 15 \text{ volts drop.}$$

Power is the rate of doing work, and the work done per second in a circuit where there is a difference of pressure of 1 volt, and a current of 1 ampere is flowing, is 1 *watt*, and 1000 watts = 1 kilowatt (kW).

Power in watts = volts × amperes.

The unit of work, energy and quantity of heat is the joule (J), which is the work done when a force of 1 newton (N) moves through a distance of 1 metre (m). 1 watt (W) = 1 joule per second (J/s). A Newton is that force which, acting on a mass of 1 kilogram (kg), will give it an acceleration of 1 metre per second per second (1 m/s^2).

Example

A welding generator has an output of 80 volts, 250 amperes. Find the output in kilowatts and joules per second.

$$80 \times 250 = 20000 \text{ W} = 20 \text{ kW} = 20000 \text{ J/s}.$$

This is the actual *output* of the machine. If this generator is to be driven by an engine or electric motor, the power required to drive it would have to be much greater than this, due to frictional and other losses in the machine. A rough estimate of the power required to drive a generator can be obtained by adding on one-half of the output of the generator. For example, in the above,

estimate of power required to drive the generator = 20 + 10 = 30 kW.

It is always advisable to fit an engine which is sufficiently powerful for the

work required, and this approximation indicates an engine which would be sufficient for the work including overloads.

Energy is expended when work is done and it is measured by the product of the power in a circuit and the time for which this power is developed. If the power in a circuit is 1 watt for a period of 1 hour, the energy expended in the circuit is 1 watt hour.

The practical unit of energy is 1000 watt hours, or 1 kilowatt hour (kWh), usually termed 1 Unit. This is the unit of electrical energy for consumption purposes, and is the unit on which supply companies base their charge.

Example

An electric motor driving a welding generator is rated at 25 kW. Find the cost of running this on full load, per day of 6 hours, with electrical energy at 2.5p per Unit.

Energy consumed in 6 hours = 25 × 6 = 150 kWh or Units.

Cost per day = 150 × 2.5 = £3.75p.

Resistance of a conductor

The resistance of R ohms of a conductor is proportional to its length l and inversely proportional to its cross sectional area a, that is $R \propto l/a$. Thus the longer a cable the greater its resistance, and the smaller its cross-sectional area the greater its resistance. To reduce the voltage drop in any cable it should be as short as possible and of as large a cross-sectional area as possible.

Measurement of resistance and insulation resistance. Continuity

The instruments used are usually moving coil type with built-in rectifiers for use with alternating current. There is an internal battery for power supply.

For the measurement of resistance, the range, in ohms or megohms ($1\ \text{M}\Omega = 10^6\ \Omega$), is selected on the multi-position switch on the instrument. The two terminals are connected to two prods or clips and these are connected to the resistor, the reading being given digitally or on an analogue scale with pointer. This scale usually has the zero to the right because the instrument is measuring current, which increases with decreasing resistance. Multi-range instruments have multi-divided scales comprising volts, millivolts, amperes, milliamperes, etc., according to the instrument, and the range required is selected by means of a rotary switch on the instrument. For continuity testing the instrument has an internal battery and buzzer which operates when the circuit is continuous.

The insulation resistance of a cable decreases as its length increases and is measured in ohms or megohms. For lighting or power circuits the test

is generally made between each conductor and earth and between conductors (with all switches in the circuits in the 'off' position), by means of an insulation tester which often includes a continuity tester (with buzzer). The insulation resistance is tested at twice the operating voltage of the circuit, instruments being available with test voltages of 500, 1000 and 2500 V. The test on a lighting circuit may give a satisfactory reading of 1 MΩ from conductor to earth. (The actual voltage of a welding circuit seldom exceeds 100 V and low voltage instruments are available.) Readings may be analogue on a scale or digital or both, a multi-position switch giving the required range. A carbon–manganese battery may be the source of power with internal circuitry giving the required output. Other instruments may have a built-in hand-driven generator to five voltages of 500 or 1000 V. Most instruments show the open-circuit or infinity (∞) resistance to the left of the scale. Note that all tests must conform to the current rules and regulations of the Institution of Electrical Engineers.

Heating effect of a current

When a current flows through a conductor, heat, which is a form of energy, is generated because the conductor has some resistance. The heat generated is proportional to the power in the circuit and the duration for which this power is developed. The power is the product of the volts drop and the current so that:

heat developed $\propto$ power $\times$ time $\propto$ volts drop $\times$ current $\times$ time.

If the current is I amperes flowing for t seconds with V volts drop in a circuit of resistance R ohms, then

heat in joules $= V \times I \times t = I^2 \times R \times t$ (since by Ohm's law $V = I \times R$),

so that the heating effect $\propto$ (current)^2.

Thus if the current in any cable is doubled, four times as much heat is generated in a circuit; if the current is trebled, nine times as much heat is generated. This loss due to the heating effect is known as the I^2R loss

The following definitions are useful.

An ampere is that steady current which, passing through two parallel straight, infinitely long conductors of negligible cross-sectional area, one metre apart in a vacuum, produces a force of 2×10^{-7} newtons per metre length on each conductor.

The ohm is that resistance in which a current of 1 ampere flowing for 1 second generates 1 joule of heat energy.

The volt is the potential difference across a resistor having a resistance of 1 ohm and carrying a current of 1 ampere.

Overload protection. One use of the heating effect of a current is to protect electrical apparatus from excessive currents which would cause damage (Fig. 4.8). A heating coil of nickel-chrome wire carries the main current to the apparatus, for example it may be the input supply to a welding transformer. Near the coil is a bi-metal strip made of two thin metal strips, which can be of brass and a nickel alloy rolled together to form a single laminated strip. The brass, which has the greater coefficient of expansion, is placed on the side nearer the heater. When excessive currents flow the position of the strip is such that it curls away with the brass strip on the outer circumference and the contact points break, interrupting the supply to the coil which holds the main contacts in, thus disconnecting the apparatus. The fixed contact can be adjusted to be more or less in contact with the moving contact, thus varying the value of overload current required to break the circuit.

The simple electric circuit of the welding arc

If a metal arc is to be operated from a source of constant pressure, a resistance must be connected in series with it in order to obtain the correct voltage drop across the arc and to control the current flowing in the circuit. This series resistance can be of the variable type, so that the current can be regulated as required. The ammeter A in Fig. 4.9 indicates the current flowing in the circuit, while the voltmeter V_1 reads the supply voltage, and the voltmeter V_2 indicates the voltage drop across the arc. By placing the switch S on various studs, the resistance is varied, and it will be noted that one section of the resistance, marked X, cannot be cut out of circuit. This is to prevent the arc being connected directly across the supply mains. If this happened, since the resistance of the arc is fairly low, an excessive current would flow and the supply mains would be 'short-circuited', and furthermore the arc would not be stable.

The loss of energy in this series resistance is considerable, since a voltage

Fig. 4.8. Thermal overload trip.

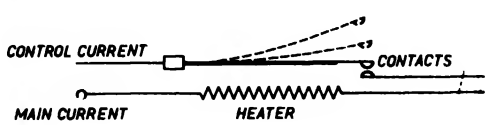
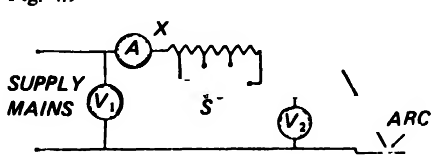


Fig. 4.9



of about 50 to 60 V is required to strike the arc, and then a voltage of about 25 to 30 V is required to maintain it. If then, as in Fig. 4.10, the supply is 60 V and 100 A are flowing in the arc circuit, with 25 volts drop across the arc, this means that there is a voltage drop of 35 V across the resistance. The loss of power in the resistance is therefore (35 × 100) W = 3.5 kW, whereas the power consumed in the arc is (25 × 100) W = 2.5 kW.

In other words, more power is being lost in the series resistance than is being used in the welding arc. Evidently, therefore, since the 60 V is required to strike the arc, some other more economical means must be found for the supply than one of constant voltage.

Modern welding generators are designed so that there is a high voltage of 50 to 60 V for striking the arc, but once the arc is struck, this voltage falls to that required to maintain the arc, and as a result only a small series resistance is required to control the current, and thus the efficiency of the operation is greatly increased. This type of generator is said to have a 'drooping characteristic'.

This can be illustrated thus: suppose the voltage of the supply is 60 V when no current is flowing, that is, 60 V is available for striking the arc; and suppose that the voltage falls to 37 V when the arc is struck, the voltage drop across the arc again being 25 V and a current of 100 A is flowing (Fig. 4.11). The power lost in the resistance is now only (12 × 100) W or $1\frac{1}{5}$ kW, which is just less than one-half the loss in the previous example, when a constant voltage source was used.

Contact resistance. Whenever poor electrical contact is made between two points the electrical resistance is increased, and there will be a drop in voltage at this point, resulting in heat being developed. If bad contact

Fig. 4.10

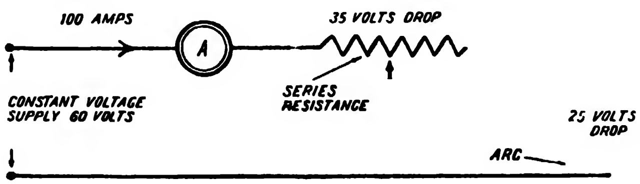
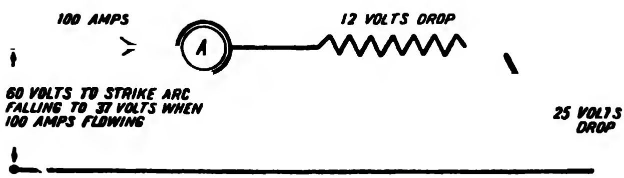


Fig. 4.11



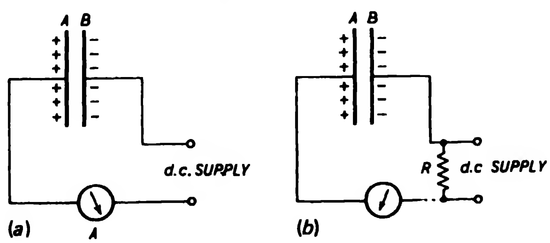
occurs in a welding circuit, it often results in insufficient voltage being available at the arc. Good contact should always be made between cable lugs and the generator and the work (or bench on which the work rests). The metal plate on the welding bench to which one of the cables from the generator is fixed is often a source of poor contact, especially if it becomes coated with rust or scale. When attaching the return cable to any point on the work being welded, the point should always be scraped clean before connecting the cable lug to it, and in this respect, especially for repair work, a small hand vice, bolted to the cable lug, will enable good contact to be made with the work when the jaws are lightly clamped on any desired point, and this is especially useful when no holes are available in the article to be welded.

Capacitors and capacitance

Principle of the capacitor. Let two metal plates A and B facing each other a few millimetres apart, be connected through a switch and centre zero milliammeter to a d.c. source of supply (Fig. 4.12*a*). When the switch is closed, electrons flow from A to B through the circuit, and A has a positive and B a negative charge. The needle of the meter moves in one direction as the electrons flow and registers zero again when the p.d. between A and B equals that of the supply. There is no further flow of current and the plates act as a very high resistance in the circuit. The number of electrons transferred is termed the charge, unit charge being the coulomb, which is the charge passing when a current of 1 ampere flows for 1 second.

Between the plates in the air, which is termed the dielectric, there exists a state of electrical stress. If the two plates are now brought quickly together (with the switch still closed) the needle flicks again in the same direction as previously, showing that more electrons have flowed from A to B and the plates now have a greater charge. When the plates are brought nearer together the positive charge on A has a greater neutralizing effect on the charge on B so that the p.d. between the plates is lowered and a further flow of electrons takes place. This arrangement of plates separated by a space of

Fig. 4.12. (*a*) Charging current, (*b*) discharging current.



dielectric is termed a capacitor and its function is to store a charge of electricity.

Now disconnect the plates from the supply by opening the switch and short-circuit the plates through a resistor *R* (Fig. 4.12*b*). Electrons flow from *B* to *A*, the needle of the meter flicks in the opposite direction, and the charge of electricity which is transferred represents the quantity of electricity which the capacitor will hold and is termed its capacitance. The capacitor is now discharged and in practice the quantity of charge passing is determined by discharging it through a ballistic galvanometer. The moving portion of this instrument has considerable mass and therefore inertia and the angle through which the movement turns is proportional to the quantity of electricity which passes.

Using the same plates as before and about 2 mm apart, charge them through a ballistic galvanometer and note the angle of deflection. Now slide a piece of glass, bakelite, mica or other insulating medium between the plates and after discharging the capacitor repeat the experiment. It will be noted that the angle of deflexion of the meter has increased showing that the capacitance of the capacitor has increased due to the presence of the different dielectric. Similarly if the plates are made larger the capacitance is increased, so that the capacitance depends upon:

(1) The area of the plates. The greater the area, the greater the capacitance.
(2) The distance apart of the plates. The nearer together the plates the greater the capacitance.
(3) The type of dielectric between the plates. Glass, mica and paper give a greater capacitance than air.

Dielectric strength. If the p.d. across the plates of a capacitor is continuously increased, a spark discharge will eventually occur between the plates puncturing the dielectric (if it is a solid). If the dielectric is, say, mica or paper, the hole made by the spark discharge means that at this point there is an air dielectric between the plates, and now it will not stand as high a p.d. across the plates as it did before breakdown.

When capacitors are connected in series (Fig. 4.13*b*) the sum of the voltage drop across the individual capacitors equals the total volts drop across the circuit. When capacitors are in parallel (Fig. 4.13*a*) the volts drop across each is the same as that of the supply but the total capacitance is equal to the sum of their individual capacitance.

Capacitance is measured in farads (F). A capacitor has a capacitance of one farad if a charge of one coulomb (C) produces a potential difference of

one volt between the plates. This is a very large unit and the sub-multiple is the microfarad (μF). 10^6 μF = 1 farad.

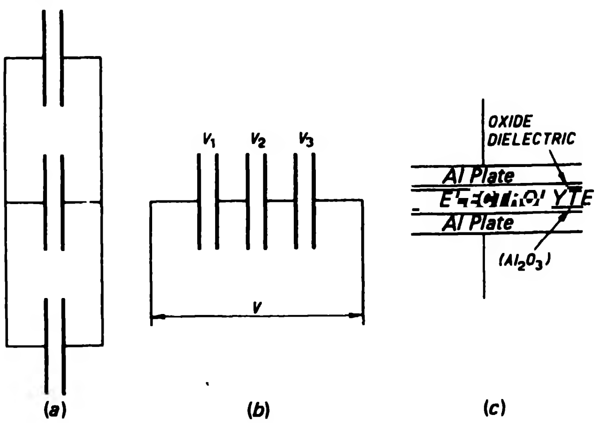
Types of capacitors. The types of capacitors usually met with in welding engineering are the Mansbridge and the electrolytic.

In the Mansbridge type two sheets of thin aluminium foil, usually long and narrow, are separated from each other by a layer of impregnated paper to form the dielectric. Connexions are made to each sheet and the whole is rolled up tightly and placed in an outer container with connexions from the two sheets, one to each terminal. The working voltage and capacitance (in μF) are stamped on the case. These capacitors are rather bulky for their capacitance.

Electrolytic capacitors, on the other hand, have very thin dielectrics and thus can be made in high capacitances but small bulk. If a sheet of aluminium foil is placed in a solution of ammonium borate and glycerine and a current is passed from the sheet to the solution, a thin film of aluminium oxide is formed on the surface of the aluminium. The microscopically thin film is an insulator and insulates the foil from the liquid which is the electrolyte, so that the current quickly falls to zero as the film of oxide forms. The current which continues to flow is the leakage current and is extremely small.

In the wet type of electrolytic, the solution is hermetically sealed in the aluminium canister which contains it, but in the dry type the solution is soaked up in gauze, and the foil, which must be absolutely clean and free from contamination, is rolled up in the gauze, one terminal being

Fig 4.13. (*a*) Capacitors in parallel. Total capacitance equals the sum of the individual capacitances. (*b*) Capacitors in series. Sum of volts across each equals total drop across the circuit. (*c*) a.c. electrolytic capacitor.



connected to the foil and the other to the gauze, and the whole hermetically sealed in an outer case. When connected to a d.c. supply, the initial current which passes forms the dielectric film and the capacitor functions. The thinner the dielectric, the greater the capacitance, so that for a safe working voltage of say 25 V, the capacitor will be of small bulk even for a capacitance of 1000 μF. The foil terminal is positive so that the capacitor is polarized, and wrong polarity connexions will ruin the unit.

The capacitor just described cannot be used on a.c. with its continuously changing polarity but an a.c. electrolytic capacitor has been developed which, although not continuously rated, is very suitable for circuits where intermittent use is required, as for example the series capacitor which is used to suppress the d.c. component of current when a.c. TIG welding aluminium and its alloys. This type consists of two aluminium electrodes, in foil form separated by gauze soaked in the electrolyte (Fig. 4.13*c*). When a current flows in either direction, a molecularly thin film of aluminium oxide is formed on each sheet, providing the dielectric. This film is not a perfect insulator and a leakage current flows, which increases with increasing voltage. This leakage current quickly makes good any imperfections in the oxide film but the voltage rating of the unit is critical since excess voltage will produce excess leakage current and lead to breakdown. Capacitors of this type are of small size for capacitances of 1000 μF, and when connected in parallel, are suitable for a.c. circuits in which large currents are flowing, as in welding.

Magnetic field

Pieces of a mineral called lodestone or magnetic oxide of iron possess the power of attracting pieces of iron or steel and were first discovered centuries ago in Asia Minor. If a piece of lodestone is suspended by a thread, it will always come to rest with its ends pointing in a certain direction (north and south); and if it is rubbed on a knitting-needle (hard steel), the needle then acquires the same properties. The needle is then said to be a magnet, and it has been magnetized by the lodestone. Modern magnets of tungsten and cobalt steel are similar, except that they are magnetized by a method which makes them very powerful magnets.

Suppose a magnetized knitting-needle is dipped into some iron filings. It is seen that the filings adhere to the magnet in large tufts near its ends. These places are termed the poles of the magnet. If the magnet is now suspended by a thread so that it can swing freely horizontally, we find that the needle will come to rest with one particular end always pointing northwards. This end is termed the north pole of the magnet, while the other end which points south is termed the south pole.

Let us now suspend two magnets and mark clearly their north and south poles, then bring two north poles or two south poles near each other. We find that they repel each other. If, however, a north pole is brought near a south pole, we find that they attract each other, and from this experiment we have the law: *like poles repel, unlike poles attract* (Fig. 4.14).

If we attempt to magnetize a piece of soft iron (such as a nail), by rubbing it with a magnet, it is found that it will not retain any magnetic properties. For this reason hard steel is used for permanent magnets.

Iron filings provide an excellent means of observing the area over which a magnet exerts its influence. A sheet of paper is placed over a bar magnet and iron filings are sprinkled over the paper, which is then gently tapped. The filings set themselves along definite lines and form a pattern. This pattern is shown in Fig. 4.15.

In the three-dimensional space around the magnet there exists a magnetic field and the iron filings set themselves in line with the direction of action of the force in the field, that is, in the direction of the magnetic flux.

It should be noted that the iron filings map represents the field in one plane only, whereas the flux exists in all directions around the magnet. Fig. 4.16 shows the flux due to two like poles opposite each other and clearly indicates the repulsion effect, while Fig. 4.17 shows the attraction between

Fig. 4.14

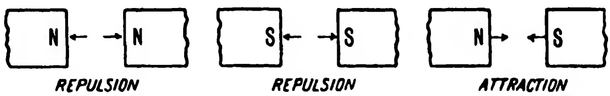
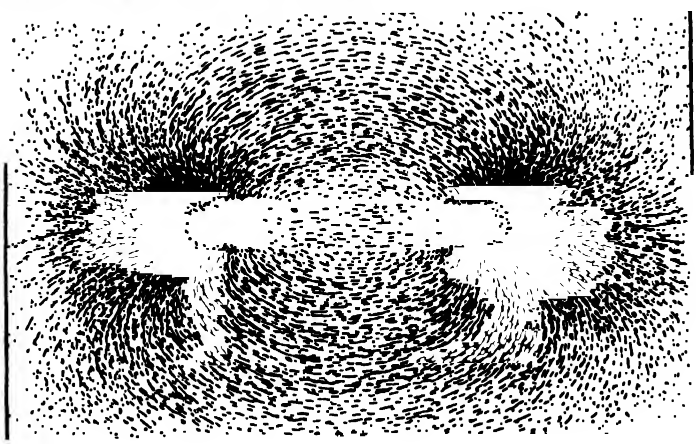


Fig. 4.15. Magnetic field of a bar magnet.



two unlike poles. The normal flux per unit area (B) is termed the flux density.

Magnetic field due to a current

If a magnetic needle (or compass needle) is brought near a wire in which a current is flowing, it is noticed that the needle is deflected, indicating that there is a magnetic field around the wire. If the wire carrying the current is passed through the centre of a horizontal piece of paper and an iron filing map made, it can be seen that the magnetic lines of force are in concentric circles around the wire (Fig. 4.18).

Two wires carrying currents in the same direction will attract each other, due to the attraction of the fields, while if the currents are flowing in opposite directions, there is repulsion between the wires.

The magnetic flux round a wire carrying a current is used to magnetize

Fig. 4.16. Repulsion between like poles

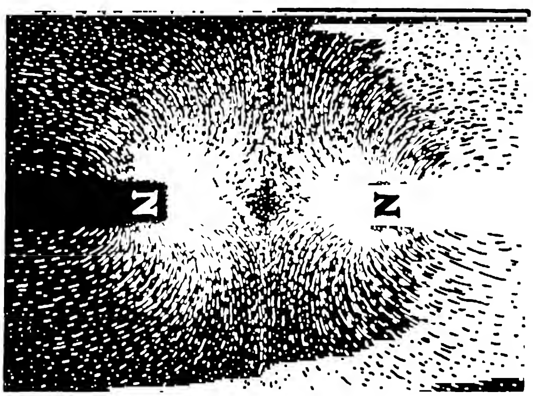
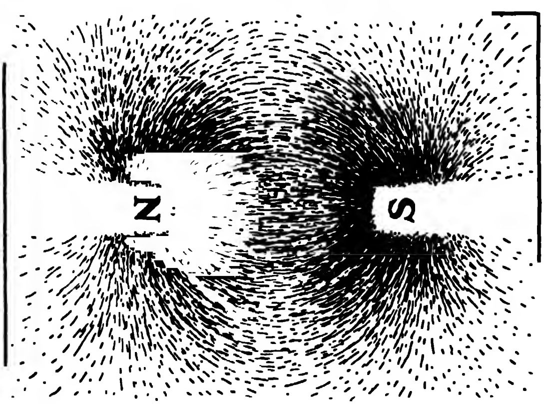


Fig. 4.17. Attraction between unlike poles.



pieces of soft iron to a very high degree, and these are then termed electromagnets.

Many turns of insulated wire are wrapped round an iron core and a current passed around the coil thus formed. The iron core becomes strongly magnetized, and we find that the greater the number of turns and the larger the current, the more strongly is the core magnetized. This is true until a point termed 'saturation point' is reached, after which increase in neither the number of turns nor in the current will produce any increase in intensity of the magnetism.

That end of the core around which the current is passing clockwise, when we look at it endways, exhibits south polarity, while the end around which the current passes anti-clockwise exhibits north polarity (Figs. 4.19, 4.20).

Relays and contactors

A solenoid is a multi-turn coil of insulated wire wound uniformly on a cylindrical former and the magnetic flux due to current flowing in a single-turn coil and in a solenoid is shown in Fig. 4.21*a* and *b*. The flux has greatest intensity within the centre of the coil and if a piece of soft iron is

Fig. 4.18

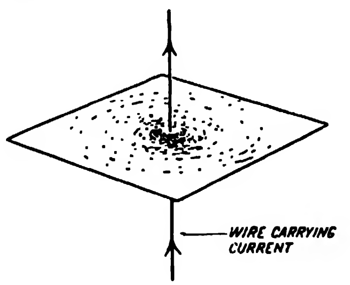


Fig. 4.19

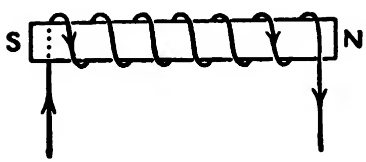
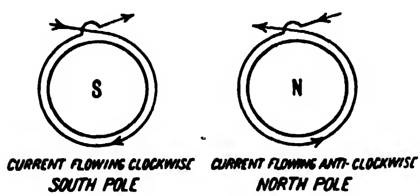


Fig. 4.20



placed with one end just inside the coil it becomes magnetized by induction and drawn within the coil when a current flows (Fig. 4.22). In semi-automatic processes such as TIG and MIG, it is important that the various services required, namely, welding current, gas and water, can be controlled from a switch on the welding gun or welding table. This remote-control operation is performed by the use of relays, by which small currents in the control circuit, often at lower voltages than the mains (110 V a.c., 50 V d.c.), operate contactors which make and break the main circuit current.

The control wires to the switch are light and flexible and they control the main welding current, which may be several hundred amperes. Fig. 4.23 shows a simple layout for the control of a welding current circuit. When *M* is pressed, the control current passes through *M* and the contactor coil is energized, the iron core moves up, the main contacts are bridged and the main current flows. Also the contacts *S* are made and because they

Fig. 4.21. (*a*) Magnetic flux due to a single turn of wire carrying a current. (*b*) Magnetic flux due to a coil of wire carrying a current.

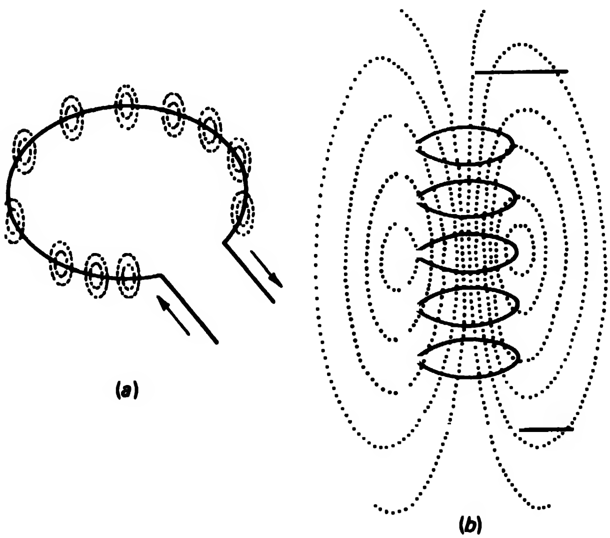
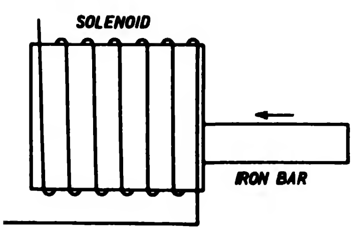


Fig. 4.22



are in parallel with those of *M*, when *M* is released, the control current passes through *P* and *S*, keeping the coil energized so that the contactors are held in. Upon pressing *P*, the coil circuit is broken and the contactors break the main circuit when the iron armature falls. Overload heaters are often fitted on two of the phases instead of three because the current in the phases is usually balanced.

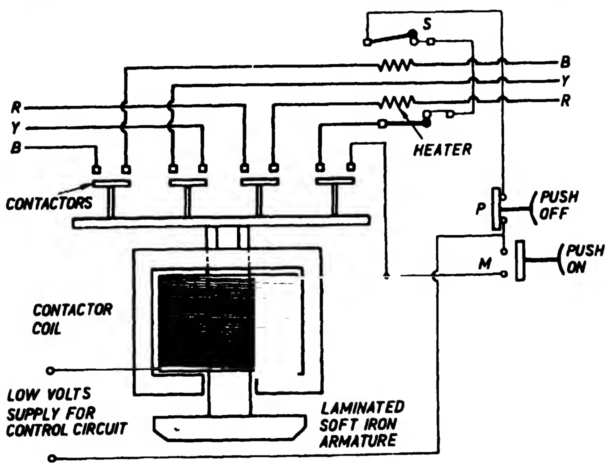
The valves are similarly operated by solenoids. When a current flows through the solenoid an armature attached to the valve moves and operates the valve.

Magnetic field of a generator

The magnetic fields of generators and motors are made in this way. The outside casing of the generator, termed the yoke, has bolted to it on its inside the iron cores called *pole pieces*, over which the magnetizing coils, consisting of hundreds of turns of insulated copper wire, fit. To extend the area of influence of the flux, pole shoes are fixed to the pole pieces (or made in one with them), and these help to keep the coils in position. Generators may have 2, 4 or more poles, and the arrangement of a 2- and a 4-pole machine is sketched in Fig. 4.24.

It will be noticed that a north and south pole always come alternately, thus producing a strong flux density where the conductors on the rotating portion of the machine are fixed. The magnetic circuit is completed through the yoke. The coils are connected so that the current passes through them alternately clockwise and anti-clockwise when looked at from the inside of the generator, so as to give the correct polarity (this can be tested by using a

Fig. 4.23. Relay control with overload protection on two phases.



compass needle), and the current which flows through the coils is termed the magnetizing or *excitation* current (Fig. 4.25).

The larger the air gap between the poles of an electro-magnet the stronger must the magnetizing force be to produce a given flux in the gap. This means that the greater the gap between the pole pieces of a machine and the rotating iron core, called the armature, the greater must the magnetizing current be to produce a field of given strength. For this reason the gap between pole pieces and rotating armature must be kept as small as possible, yet without any danger of slight wear on the bearings causing the armature to foul the pole pieces (the machine is then said to be pole bound). In addition, this gap should be even at each pole piece all round the armature. Excessive air gaps result in an inefficient machine.

The electric field of a d.c. electric motor is similar to that of a generator. Many fractional horse power motors, for example like those used for wire feed in MIG welding, have a magnetic field(s) supplied by permanent magnets. Since these have no windings it greatly simplifies the motor and for FHP motors their reliability and the strength of the permanent magnets makes this method very satisfactory.

Fig. 4.24

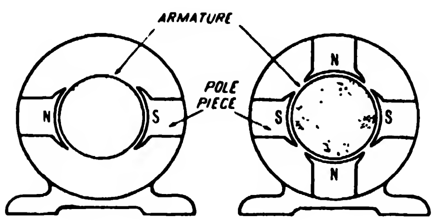
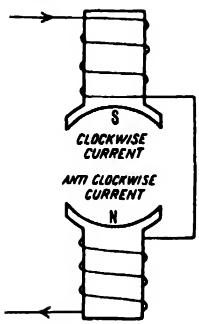


Fig. 4.25



Generation of a current by electrical machines

The following explanation of the principle of operation of a generator is an outline only and will serve to give the operator an idea of the function of the various parts of the machine.

For a current to be generated we require (1) a magnetic flux, (2) a conductor, (3) motion (producing change of magnetic flux).

The magnetic field causes a magnetic flux to be set up, and the conductor is surrounded by this flux. Any change of flux caused by the change in position of the conductor or by change in value of the field will cause a current to be generated in the conductor.

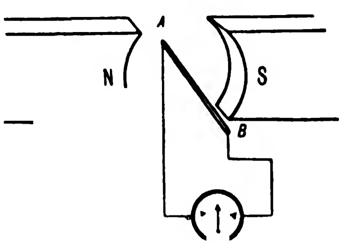
Generation of alternating current

Let us consider the first case. N and S (Fig. 4.26) are the poles of a magnet and *AB* is a copper wire whose ends are connected to a milliammeter. (This is an instrument that will measure currents of the order of $\frac{1}{1000}$ amp.) If the conductor *AB* is moved upwards, we find that the needle of *A* swings in one direction, while if *AB* is moved downwards, it swings in the opposite direction. By moving *AB* up and down, we generate a current that flows first in one direction, *B* to *A*, and then in the other direction, *A* to *B*. This is termed an alternating current, and the current is said to be induced in the conductor.

Note. The rule by which the direction of the current in a conductor is found, when we know the direction of the field and the motion, is termed *Fleming's right-hand rule*. This can be stated thus. 'Place the thumb, first finger and second finger of the right hand all at right angles to each other. Point the first finger in the direction of the flux from N to S and turn the hand so that the thumb points in the direction of motion of the conductor. Then the second finger points in the direction in which the current will flow in the conductor.' Fig. 4.27 makes this clear.

Instead of moving the conductor up and down in this way, the method used for generation is to make the conductor in the form of a coil of several

Fig. 4.26



turns and rotate it, and if the coil is wound on an iron core, the field is greatly strengthened and much larger currents are generated.

The ends of the coil are connected to two copper rings mounted on the shaft, but insulated from it, and spring-loaded contacts called brushes bear on these rings, leading the current away from the rotating system (see Fig. 4.28).

From the brushes X and Y, wires lead to the external circuit, which has been shown as a coil of wire, OP, for simplicity.

When the coil is rotated clockwise, AB moves up and CD down. By applying Fleming's rule we find that the current flows from B to A in one conductor and from C to D in the other, as shown by the arrows (Fig. 4.29a). The current will then leave the machine by slip ring Y and flow through the external circuit from O to P and return via slip ring X.

Fig. 4.27. Fleming's right-hand rule.

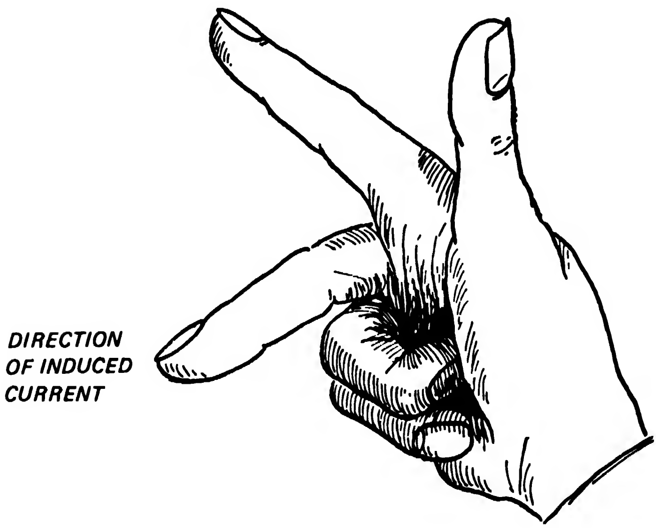
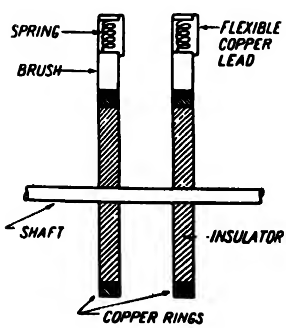


Fig. 4.28



When the coil has been turned through half a turn, as shown in Fig. 4.29*b*, *AB* is now moving down and *CD* up, and by Fleming's rules the currents will now be from *D* to *C* in one conductor and from *A* to *B* in the other. This causes the current to leave by a slip ring *X* and flow through the external circuit from *P* to *O*, returning via slip ring *Y*. If a milliameter with centre zero is placed in the circuit in place of the coil *OP*, the needle of the instrument flicks to one side during the first half turn of the coil and to the other side during the second half turn.

Evidently, therefore, in one revolution of the coil, the direction of the current generated by the coil has been reversed. No current is generated when the coil is passing the position perpendicular to the flux, while maximum current is generated when the coil is passing the position in the plane of the flux. This is illustrated in Fig. 4.30.

Fig. 4.29

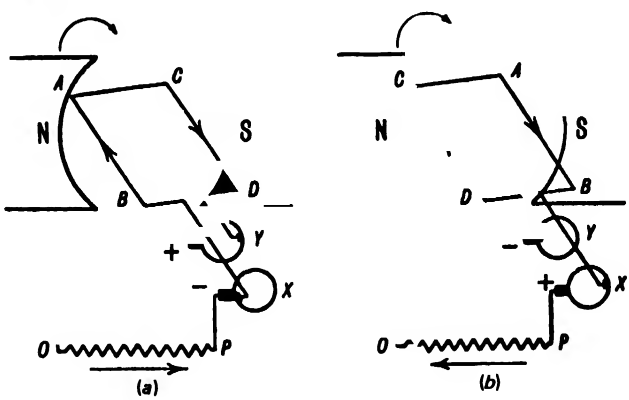
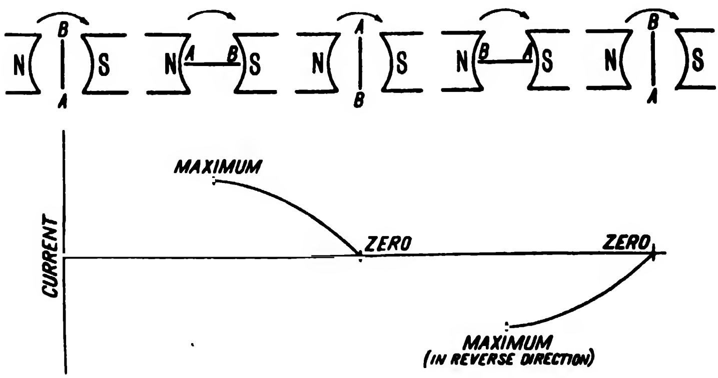


Fig. 4.30



One complete rotation of the coil has resulted in the current starting at zero, rising to a maximum, falling to zero, reversing in direction and rising to a maximum and then falling again to zero. This is termed a complete *cycle*, and the number of times this occurs per second (that is, the number of revolutions which the above coil makes per second) is termed the frequency of the alternating current. 1 cycle per second is known as 1 hertz (Hz), named after the German physicist who discovered electro-magnetic waves.

Alternating currents in this country are usually supplied at 50 Hz. In America 60 Hz is largely used. Evidently a.c. has no definite polarity, that is, first one side and then the other becomes +ve or −ve.

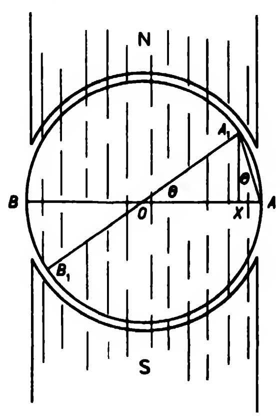
Sinusoidal wave form

The current and voltage generated by a coil rotating in a magnetic field follow a curved path from zero to maximum positions. This curve is known as a sine curve and the voltage and current waves are termed sinusoidal waves.

The e.m.f. generated in a conductor is proportional to the rate at which the conductor cuts the magnetic flux. If the conductor moves across the lines of force so that the flux linkage changes, an e.m.f. is generated. If the conductor moves along a line of force there is no change of flux linkage and no e.m.f. is generated. This can be illustrated in the following way.

The coil AB (Fig. 4.31) is rotating anti-clockwise between the poles N and S of a magnet and the flux is shown in dotted lines. Let the coil turn from AB to A_1B_1 through an angle θ. From A_1 drop a perpendicular A_1X on to AB and join AA_1. In moving from A to A_1 it can be considered that the conductor has moved from A to X across the flux and from X to A_1

Fig. 4.31



along the flux path. The e.m.f. generated is thus proportional to AX, no e.m.f. being generated in the movement from X to A_1.

But

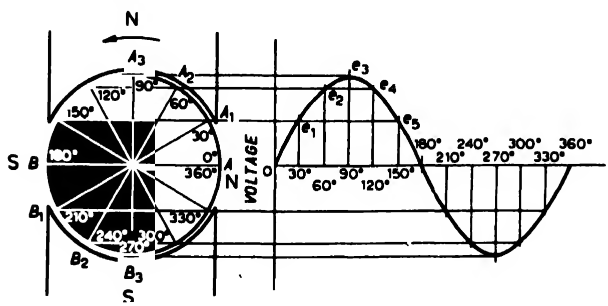
$$\frac{AX}{AA_1} = \sin\theta,$$

$$\therefore AX = AA_1 \sin\theta$$

and since angle AA_1X = angle AOA_1, the e.m.f. is proportional to the sine of the angle through which the coil is rotated and hence the generated e.m.f. will be a sine curve.

To draw this curve the coil AB (Fig. 4.32) is again rotated anti-clockwise between the magnetic poles N and S. Divide the circle into 30° sectors as shown and on the horizontal axis (abscissa) of the graph, divide the 360° of one rotation of the coil into 30° equal divisions. The vertical axis or ordinate represents the e.m.f. generated. When the coil is in the position AB the conductors are moving along the lines of force and no e.m.f. is generated. As it rotates towards A_1B_1 it begins to cut the lines immediately after leaving the AB position. A_1B_1 is the position of the coil after rotating through 30° from AB. Project horizontally from A_1 to meet the vertical ordinate through the 30° ordinate at e_1. This ordinate represents the voltage generated at this point. Let the coil rotate a further 30° to A_2B_2 and again project horizontally to meet the 60° ordinate at e_2. At A_3B_3 the conductors are moving at right angles to the field and generating maximum e.m.f. shown by the e_3 ordinate. Further rotation of the coil results in a reduction of the e.m.f. to zero, e_6, when the coil has rotated through 180°. After this, further rotation produces a reversal of the e.m.f. and if the points $e_1, e_2, \ldots e_6$ are joined, the resulting curve, is termed as sine wave and represents the generated voltage or e.m.f. Since the current is proportional to the voltage the current wave is also sinusoidal.

Fig. 4.32



Root mean square value of an alternating current

Since an alternating current or voltage is continuously changing from zero to a maximum value some method must be selected to define the true value of an alternating current or voltage. This is done by comparing the direct current required to produce a given heating effect with the corresponding alternating current which produces the same heating effect.

An alternating current of I amperes is that current which will produce the same heating effect as a direct current of I amperes.

If an alternating current equivalent to I amperes d.c. flows through a resistor $R\Omega$ for t seconds, then the energy generated $= I^2Rt$ joules (p. 176). Let OXY (Fig. 4.33) be the wave form of this current. Divide it into n areas on equal bases, each base being therefore t/n since OY represents the time in seconds. Draw the mid-ordinates $i_1, i_2, i_3 \ldots i_n$ for each area. The energy represented by the first area is $i_1^2R \times t/n$ (mid-ordinate rule for areas).

Energy for second area is $\quad i_2^2R \times \dfrac{t}{n}$,

Energy for third area is $\quad i_3^2R \times \dfrac{t}{n}$,

Energy for nth area is $\quad i_n^2R \times \dfrac{t}{n}$.

Therefore the total energy

$$= i_1^2R \times \frac{t}{n} + i_2^2R \times \frac{t}{n} + i_3^2R \times \frac{t}{n} + \ldots i_n^2R \times \frac{t}{n} \text{ joules}$$

$$= Rt \quad \frac{i_1^2}{n} + \frac{i_2^2}{n} + \frac{i_3^2}{n} + \ldots \frac{i_n^2}{n} \text{ joules,}$$

but the total energy is I^2Rt joules, therefore

$$I^2Rt = Rt \quad \frac{i_1^2}{n} + \frac{i_2^2}{n} + \frac{i_3^2}{n} + \ldots \frac{i_n^2}{n}$$

$$\therefore \quad I^2 = \frac{i_1^2}{n} + \frac{i_2^2}{n} + \frac{i_3^2}{n} + \ldots \frac{i_n^2}{n}$$

$$\therefore \quad I = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 + \ldots i_n^2}{n}}$$

That is, the true, effective or virtual value I amperes of the alternating current equals the square root of the mean value of the squares of the current ordinates, or

I = square root of the mean squares, termed the rms value.

If the current wave is sinusoidal this value is 0.707 of the maximum or peak

value so that if I_m is the maximum value of the current, the true or rms value is

$$I = 0.707\ I_m \text{ (Fig. 4.34).}$$

If an alternating current of maximum value I_m is flowing in a circuit its effect is the same as that of a direct current of value 0.707 I_m.

Similarly with an alternating voltage. If the root mean square (rms) value of a supply is 240 V, the maximum value of the voltage is given by

$$V = 0.707 \cdot V_m$$
$$240 = 0.707\ V_m$$
$$V_m = \frac{240}{0.707} = 340 \text{ V.}$$

This explains why it is possible to get a much greater shock from an a.c. supply of the same rated voltage as a d.c. supply and hence why the earthing of a.c. apparatus is so important. An a.c. supply is always designated by its rms value unless otherwise stated.

Fig. 4.33

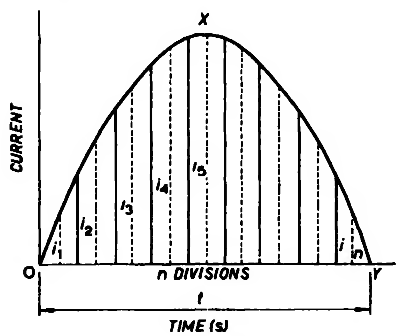
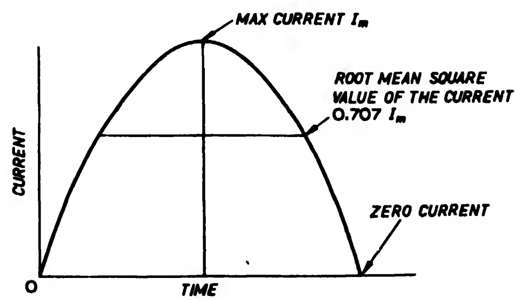


Fig. 4.34



Generation of direct current

By an ingenious yet simple device called the commutator (current reverser), this generated alternating current can be changed to direct current, that is, to a current flowing only in one direction. Instead of slip rings, two segments of copper are mounted on the circumference of the shaft, as shown in Fig. 4.35, being separated from each other by a small gap. Brushes bear on these segments as they did on the slip rings previously. As the coil rotates, the segments will first make contact with each brush in turn and thus reverse the connexions to the external circuit.

In Fig. 4.36*a* and *b*, the conductors are lettered as before, but *AB* is connected to one segment and *CD* to the other. Brushes *X* and *Y* bear on the segments and are connected to the external circuit *OP*. Upon rotating the coil, the current flows in the coil as previously. It leaves by brush *Y* (Fig. 4.36*a*), flows through the external circuit from *P* to *O* and back via brush *X*. In Fig. 4.36*b*, when the coil has turned through half a turn, the connexions of the coils to the brushes have been reversed by the segments of the

Fig 4.35

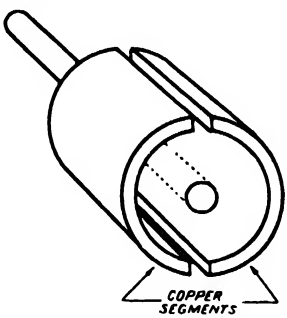
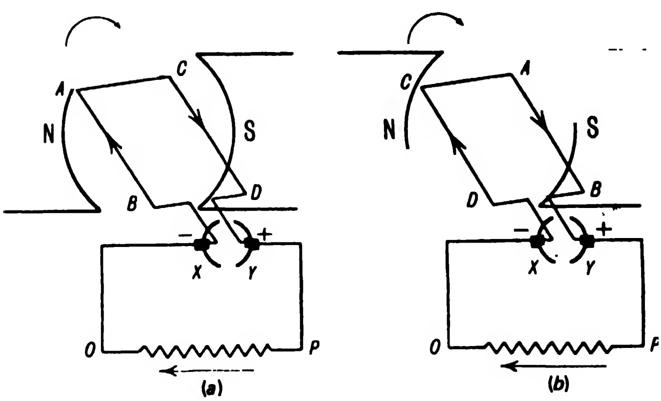


Fig. 4.36



commutator and the current again leaves via brush *Y*, through the external circuit in the same way, from *P* to *O*, returning via brush *X*. Thus, though the current in the coil has alternated, the current in the external circuit is uni-directional, or 'direct current' as it is called. Since the current flows from *Y* to *X*, through the external circuit, *Y* is termed the positive pole and *X* the negative pole.

The brushes pass over the joints or gaps between the segments as the coil passes through the position perpendicular to the field, i.e., when no current is generated; thus there is no spark due to the circuit being broken whilst the current is still flowing (Figs. 4.37, 4.38).

The current from a direct current generator with a single coil of several turns, as we have just considered, would be a series of pulsations of current, starting at zero, rising to a maximum and decreasing to zero again, but always flowing in the same direction, as shown in Fig. 4.39.

If, now, a second coil is wound and mounted on the shaft at right angles

Fig. 4.37. Maximum current position.

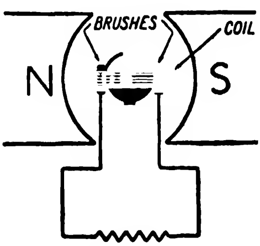


Fig. 4.38. Zero current.

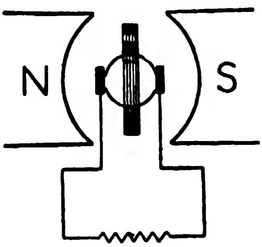
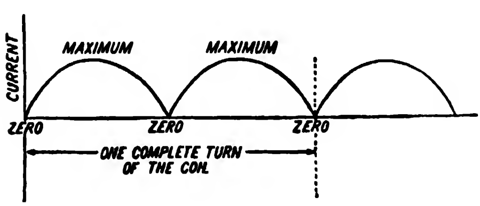


Fig. 4.39



to the first coil and its ends connected to a second pair of commutator segments, the maximum current in one coil will occur when the other coil has zero current; and since there are now four commutator segments, each now only extends round half the length that it did previously. The resulting current from the two coils *A* and *B* will now be represented by a thick line; the dotted portion will no longer be collected by the brushes, because of the shortened length of the commutator segment (Fig. 4.40).

By increasing greatly the number of coils (and consequently the number of commutator segments, since each coil has two segments), the pulsating current can be made less and less, that is, the effect is a steady flow, as shown in Fig. 4.41.

It is not necessary here to enter into details of the various methods of connecting the coils to the segments. Full details of these are given in text-books on electrical engineering. The voltage of a machine is increased by increasing the number of turns of wire in each coil, while the current output of a machine is increased by increasing the total number of coils in parallel on the machine. The output of a machine can also be increased by increasing the speed of the machine and also by increasing the strength of the magnetic flux.

By increasing the number of poles of a machine, its voltage can be increased, while yet keeping its speed the same. Machines of 4 and 6 poles are quite common. In this case there are the same number of sets of brushes as there are poles, i.e. 4 poles, 4 sets of brushes, and so on, and these brushes are connected alternately, as in Fig. 4.42, so as to give + ve and − ve poles.

Fig. 4.40

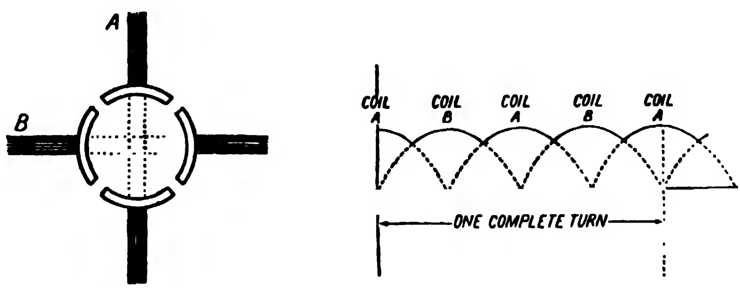
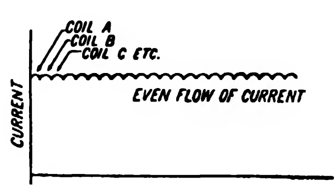


Fig. 4.41



Most welding generators are either 2- or 4-pole. For a given output, the greater the number of poles the slower the speed of the machine. As a rule a machine is designed to operate at a given speed, but the output voltage is varied by a resistor known as the field regulator (see later).

Rectifiers

One method of changing a.c. to d.c. is by the use of an a.c. motor driving a d.c. generator. Static rectifiers perform this operation without the use of moving parts and the types having welding applications are (1) selenium and (2) silicon, and they are used for supplying d.c. for manual metal arc, TIG, MIG, CO_2, etc.

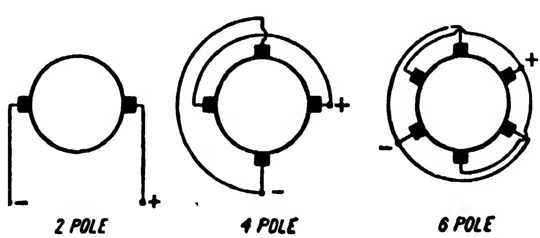
A rectifier should have a low resistance in one direction (forward) so as to allow the current to pass easily, and a high resistance in the opposite direction (reverse) so that very little current will pass. In practice all rectifiers pass some reverse current and this increases with rising temperature so that cooling fins are usually fitted.

Selenium rectifier. This type has largely displaced the copper- copper oxide rectifier for general use and consists of an iron or aluminium base disc coated with selenium, which is a non-metallic element of atomic number 34. A coating of an alloy of tin, cadmium or bismuth is deposited on to the selenium and forms the counter-electrode (Fig. 4.43*a*).

A current will flow from disc to counter-electrode but not in the reverse direction in which a high resistance is offered, so that the unit acts as a rectifier. To increase the current-carrying capacity the disc is made larger in area and units are connected in parallel. For higher voltages units are connected in series since, if the voltage drop across the unit is too high, the reverse current increases rapidly and the rectifier fails.

Semi-conductor rectifiers. This type is fitted to many of the transformer–rectifier power units for MIG and CO_2 welding. They can

Fig. 4.42. Connexions of brushes.



supply large output currents and are generally fan cooled. The following greatly simplified explanation will serve to indicate how they operate.

Silicon is a non-metallic element with four valence electrons in its outer shell. These valence electrons form a covalent bond with electrons in the outer shell of neighbouring atoms by completing the stable octet of eight electrons, which are shared between the two atoms. One way that atoms combine to form a molecule is by means of this bond. The elements neon and argon, for example, have completed outer shells of eight electrons and are therefore completely inert and form no compounds with other elements (Fig. 4.43*b*).

Antimony, phosphorus and arsenic have five electrons in the outer shell, so if a few atoms of antimony are added to a silicon crystal as an impurity (doping), four of the silicon valence electrons form four covalent bonds with four of the antimony valence electrons and there is one free electron due to each antimony atom.

These are termed donor atoms because they can donate an electron, and silicon with this type of impurity is termed n type (negative); if an electron is donated a positively charged ion remains.

Indium, gallium and aluminium have three valence electrons in the outer shell and if, say, indium is added as an impurity to silicon, these three valence electrons form covalent bonds with three of the four silicon valence electrons, but there is one electron missing so that the remaining silicon electron cannot make the fourth covalent bond. This position where the electron is missing is termed a positive hole since it will accept any available electron to form a covalent bond. When the electron enters a positive hole the atom is negatively charged and is a negative ion.

These atoms are termed acceptor atoms because they accept an electron and silicon with this type of impurity is termed p type (positive).

If a silicon crystal is formed, one half being n type and the other half p type, at the junction between the types, electrons will move from n type to p type to fill the holes and the holes will thus move from p type to n type, leaving positive ions in the n type and negative ions in the p type. There is thus a potential barrier of the order of 0.6 V set up across the junction in which there are no free holes or electrons so that electrons tending to move across it are repelled by the negative ions, and holes tending to move are repelled by the positive ions (Fig. 4.43*b*(1)).

If a potential difference is placed across the crystal (Fig. 4.43*b*(2)) so as to make the n type positive and the p type negative, this increases the effect of the potential barrier and no current can flow. This is the reverse direction of the unit.

If the p.d. is reversed, making n type negative and p type positive, the

Fig. 4.43. (*a*) Selenium rectifier.

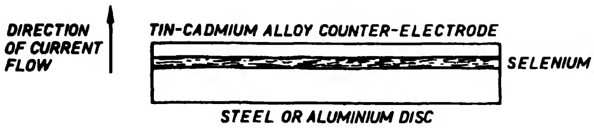
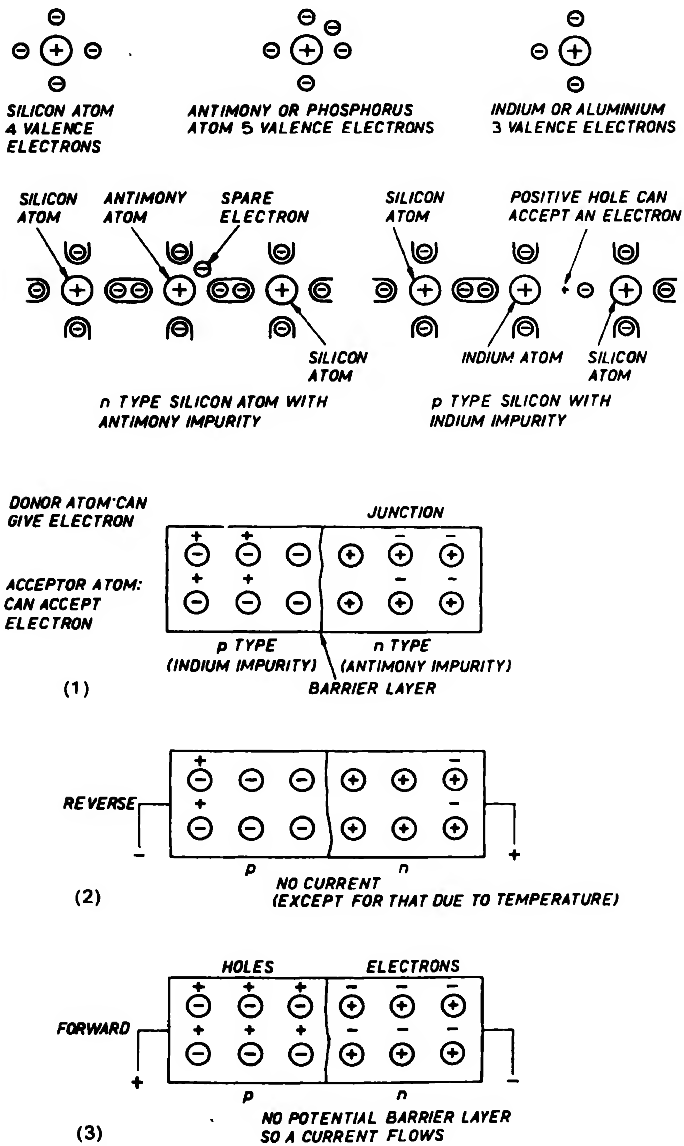


Fig. 4.43 (*b*)



applied p.d. now reduces the potential barrier effect, holes and electrons move and current flows. This is the forward direction of the current. A very small leakage current always occurs at normal temperatures due to the breaking of some of the covalent bonds but as the temperature of the junction rises, breaking of bonds increases, the carriers across the junction accelerate and remove other bonds and there comes a point when the junction breaks down and a reverse or breakdown current flows (Fig. 4.44*a*). The conductivity of both p and n type silicon is increased over pure silicon depending on the amount of doping; because the unit has two connexions it is referred to as a diode. Only one half of the a.c. wave flows, the other half being suppressed; this is termed half-wave rectification and the current and voltage consist of uni-directional pulses of 50 per second in the case of a 50 Hz supply. To obtain full-wave rectification the rectifier elements are connected in 'bridge' connexion as in Fig. 4.44*b*.

Fig. 4.44 (*a*). The diode

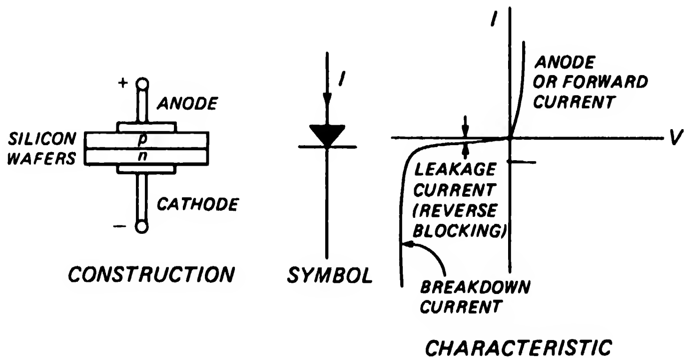
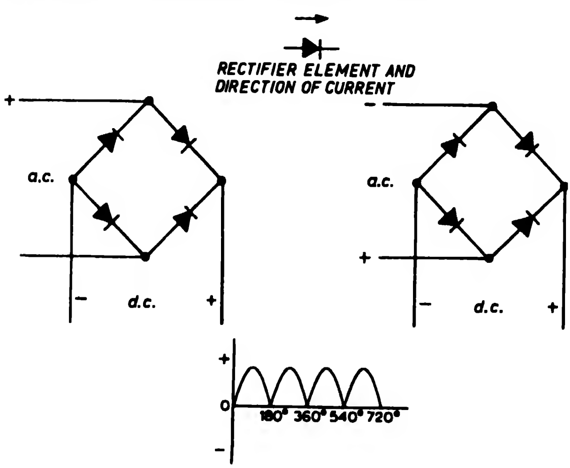


Fig. 4.44 (*b*). Single-phase full-wave rectification.



If full-wave rectification on a three-phase system is required the elements are connected as in Fig. 4.44*c*, the output of the secondary of the transformer being delta connected. This method is favoured in many cases for d.c. welding units and gives a balanced load.

Thyristors

A thyristor is a solid state switch which consumes very little power and is small and compact. Thyristors can be used for a variety of switching operations, as for example in motor control, resistance welding, circuit control and control of welding power sources. Large thyristors can carry heavy currents of up to several hundred amperes.

It is similar in construction to a solid state diode but has four elements of doped silicon in alternate layers p n p n and a gate connexion to the p element on the cathode side (Fig. 4.45*a*). If there is no connexion to the gate terminal the thyristor behaves as three diodes in series, pn np pn, so that current in either direction is blocked and with the cathode + ve (reverse) it is similar to the diode (Fig. 4.44*a*).

Fig. 4.44 (*c*)

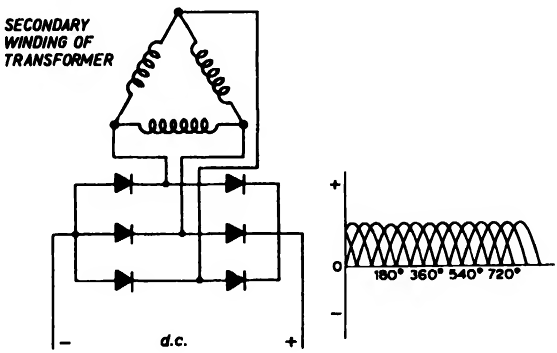
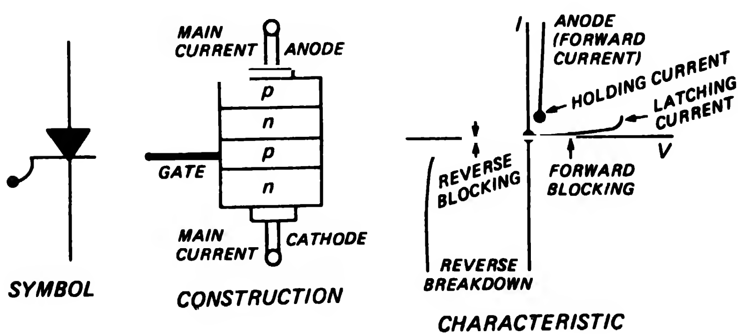


Fig. 4.45 (*a*). The thyristor.



When the anode is made + ve (forward), only a leakage current will flow until a breakdown voltage across the pn junction is reached, when almost all the voltage appears across the junction next to the cathode.

To reach the 'on' state, the thyristor, anode + ve, must attain a 'latching level', this being quite a low level of the full load value and can be obtained by putting in a gate current, forming holes in the p wafer which, with electrons from the n wafer next to the cathode, causes breakdown of the control junction next to the cathode. The anode current is now over latching level, the thyristor is now switched 'on' and in this state no further gate current is required, the thyristor remaining 'on'.

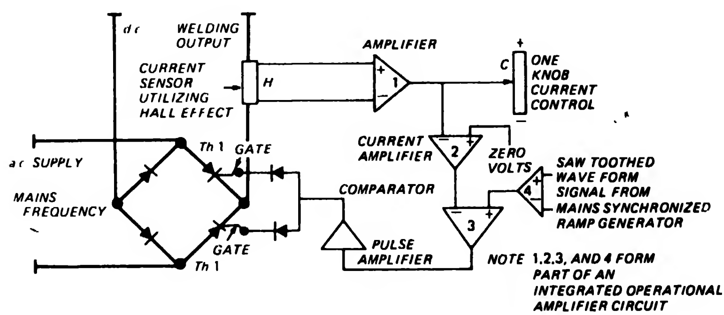
By varying the voltage bias on the gate, as for example with a potentiometer, stepless control of current is obtained from the thyristor.

Since the thyristor suppresses one half of the a.c. wave it is necessary to connect the thyristors with diodes in bridge connexion to obtain full-wave rectification as when a stepless d.c. power output is required in a welding source. This is shown in Fig. 4.45*b*. The value of welding current is set by the single knob current control *C* on the front panel. This value is compared by the control circuits with the value of output current received from *H* and the firing angle of the thyristors is altered to bring the output current to that value set by the current control.

Ignitron

The ignitron is a rectifier which has three electrodes: an anode, a cathode which is a mercury pool and an igniter, all contained in an evacuated water-cooled steel shroud. The igniter is immersed in the mercury cathode, and when a current is passed through it a 'hot spot' is formed on the surface of the pool. This acts as a source of electrons which stream to the anode if it is kept at a positive potential with respect to the

Fig. 4.45 (*b*) Thyristor control of welding current Simplified schematic diagram for one knob control of welding current using thyristors or silicon controlled rectifiers (SCR)



cathode, and a current can now flow from anode to cathode through the ignitron. It will continue doing so as long as the anode remains positive, and large ignitrons can handle currents of several thousands of amperes. The single ignitron behaves as a half-wave rectifier on an a.c. supply, and two connected in reverse parallel can operate as a switch controlling the flow of a.c. in a circuit. The arc within the unit can be struck at any point in any particular half cycle by controlling the current in the igniter circuit. The ignitron has been mostly replaced by the thyristor.

The inverter*

The inverter is an electrical device which converts d.c. to a.c., that is, it is the opposite to a rectifier.

In any welding unit the greatest weight is that of the transformer, single- or three-phase, because of the weight of the closed-circuit laminated steel magnetizable core.

As the frequency of an a.c. increases, the size and thus the weight of this laminated core becomes less because the inductance of the circuit increases with the frequency, so that if we can feed a high-frequency a.c. into a transformer so as to get a welding output voltage, this transformer will be very much less in weight than the conventional type at 50 Hz because of the reduced iron circuit.

In Fig. 4.45*c*, a three-phase 50 Hz current is first passed into a rectifier. The d.c. produced is passed into an inverter where it is converted back to a.c. but at a much higher frequency. This high-frequency (HF) a.c. is passed into a transformer which has a magnetic circuit only a fraction of that in a conventional type and it is stepped down to a suitable welding supply voltage before being passed into a bridge rectifier, the output from which is the d.c. welding supply. A unit, for example, of about 400 A output weighs about 50 kg and is thus much lighter than the conventional unit.

The control system is connected between inverter and output rectifier and a smooth arc with good starting characteristics results.

This light weight, with high output, makes it possible to transport it by car and it can be taken and used, near to the operator, on sites which may

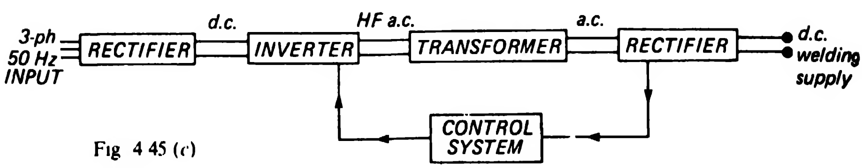


Fig. 4.45 (*c*)

* The inverter is dealt with in much greater detail in Chapter 5

otherwise need long welding cables. Longer mains cables can be used and these are lighter and more convenient.

Welding generators

Description of a typical direct-current generator

A modern direct-current welding generator consists of:

(1) Yoke with pole pieces and terminal box, and end plates.
(2) Magnetizing coils.
(3) Armature and commutator (the rotating portion).
(4) The brush gear.

The yokes of modern machines are now usually made of steel plate rolled to circular form and then butt welded at the joint. The end plates, which contain the bearing housings, bolt on to the yoke, and the feet of the machine are welded on and strengthened with fillets. The pole pieces are of special highly magnetizable iron and are bolted onto the yoke. The coils are usually of double cotton-covered copper wire, insulated and taped overall, and they fit over the pole pieces, being kept in position by the pole shoes. The armature shaft is of nickel steel and the armature core (and often the pole pieces also) is built up of these sheets of laminations of highly magnetizable iron, known by trade names such as Lohys, Hi-mag, etc. Each lamination is coated with insulating varnish, and they are then placed together and keyed on to the armature shaft, being compressed tightly together so that they look like one solid piece.

The insulating of these laminations from each other prevents currents (called eddy currents) which are generated in the iron of the armature when it is rotating from circulating throughout the armature and thus heating it up. This method of construction contributes greatly to the efficiency and cool running of a modern machine. The armature laminations have slots in them into which the armature coils of insulated copper wire are placed (usually in a mica or empire cloth insulation). The coils may be keyed into the slots by fibre wedges and the ends of the coils are securely soldered (or sweated) on to their respective commutator bars (the parts to which they are soldered are known as the commutator risers). A fan for cooling purposes is also keyed on to the armature shaft.

The commutator is of high conductivity, hard drawn copper secured by V rings, and the segments are insulated from the shaft and from each other by highest quality ruby mica. Brushes are of copper carbon, sliding freely in brush holders, and springs keep them in contact with the commutator. The tension of the springs should only be sufficient to prevent sparking. Excessive spring pressure should be avoided, as it tends to wear the

commutator unduly. The commutator and brush gear should be kept clean by occasional application of petrol on a rag, which will wash away accumulations of carbon and copper dust from the commutator micas and brush gear. All petrol must evaporate before the machine is started up, to avoid fire risk. The armature usually revolves on dust-proof and watertight ball or roller bearings, which only need packing with grease every few months. Older machines have simple bronze or white metal bearings, lubricated on the ring oil system. These need periodical inspection to see that the oil is up to level and that the oil rings are turning freely and, thus, correctly lubricating the shaft.

Connexions from the coils and brush gear are taken to the terminal box of the machine, and many welding generators have the controlling resistances and meters also mounted on the machine itself.

Connexions of welding generators

In the following sketches, magnetizing coils are shown thus: , and this represents however many coils the machine possesses, connected so as to form alternate north and south poles, as before explained. The armature, with the brushes bearing on the commutator, is shown in fig. 4.46*a*.

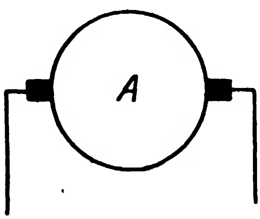
The current necessary for magnetizing the generator is either taken from the main generator terminals, when the machine is said to be self-excited, or from a separate source, when it is said to be separately excited. Welding generators are manufactured using either of these methods.

Separately excited machines

These generally take their excitation or magnetizing current from a small separate generator, mounted on an extension of the main armature shaft, and this little generator is known as the exciter. Current generated by this exciter passes through a variable resistor, with which the operator can control the magnetization current, and then round the magnetizing coils of the generator. This is shown in Figs. 4.46*b* and 4.51.

By variation of the resistance *R*, the magnetizing current and hence the strength of the magnetic flux can be varied. This varies the voltage (or pressure) of the machine and thus enables various voltages to be obtained

Fig. 4.46 (*a*)



across the arc, varying its controllability and penetration. This control is of great importance to the welder.

This type of machine gives an almost constant output voltage, irrespective of load, and thus, as before explained, would result in large losses in the series resistor, if used for welding. In order to obtain the 'drooping characteristic', so suitable for welding, the output current is carried around some *series* turns of thick copper wire, wound over the magnetizing coils on the pole pieces, and thus current passes round these turns so as to magnetize them with the opposite polarity from the normal excitation current. Fig. 4.47 shows how the coils are arranged. Consider then what happens.

When no load is on the machine, the flux is supplied from the separate exciter and the open circuit voltage of the machine is high, say 60 volts, giving a good voltage for striking. When the arc is struck, current passes through the series winding and magnetizes the poles in the opposite way from the main flux and thus the strength of the flux is reduced and the voltage of the machine drops. The larger the output current the more will the voltage drop, and evidently the voltage drop for any given output current will depend on the number of series turns. This is carefully arranged

Fig. 4.46 (*b*). Simple separately excited generator

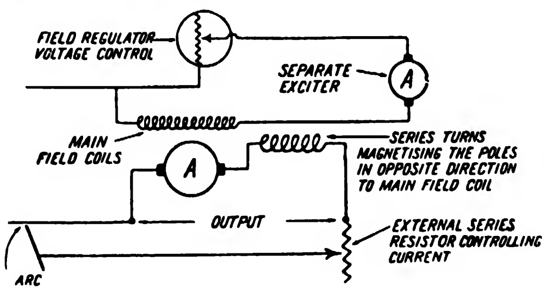
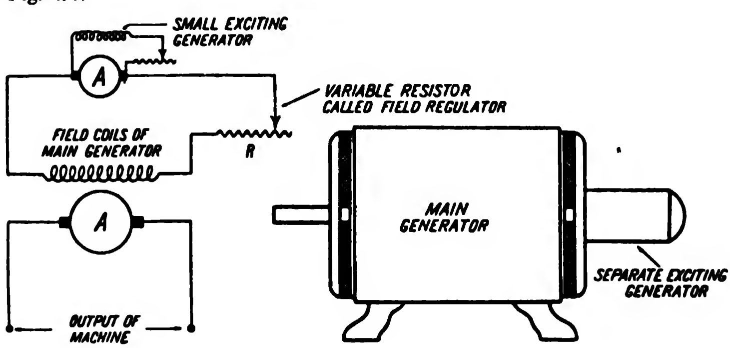


Fig. 4.47



when the machine is manufactured, so as to be the most suitable for welding purposes.

This type of machine, with control of both current and voltage, is very popular and is reliable, efficient and economical. Because the voltage available at any given instant is only slightly greater than that required to maintain the arc, only a small series resistance is required, this being fitted with the usual variable control.

Self-excited machines

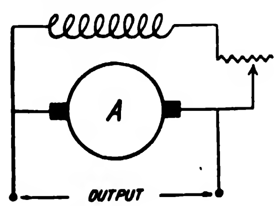
The simplest form of this type of machine is that known as the 'shunt' machine, in which the magnetizing coils take their current direct from the main terminals of the generator through a field-regulating resistor (Fig. 4.48).

There is always a small amount of 'residual' magnetism remaining in the pole pieces, even when no current is passing around the coils, and, when the armature is rotated, a small voltage is generated and this causes a current to pass around the coils, increasing the strength of the flux and again causing a greater e.m.f. to be generated, until the voltage of the machine quickly rises to normal. Control of voltage is made, as before, by the field regulator. This type of machine is not used for welding because its voltage only drops gradually as the load increases and, as before explained, this would cause a waste of energy in the external series resistor.

Again, this machine is modified for use as a welding generator by passing the output current first round series turns wound on the pole pieces, so as to magnetize them with the opposite polarity from that due to the main flux, and this results, as before, in the voltage dropping to a great extent as the load increases and, thus, the loss of energy in the external resistor is greatly reduced (Fig. 4.49). A machine of this type is termed a differential compound machine and shares with the separately excited machine the distinction of being a reliable, efficient and economical generator for welding purposes. The control of current and voltage are exactly as before.

The rest of the equipment of a direct current welding generator consists of a main switch and fuses, ammeter and voltmeter. The fuses have an

Fig. 4.48. Connexions of a simple shunt machine.



insulating body with copper contacts, across which a piece of copper wire tinned to prevent oxidation is bridged. The size of this wire is chosen so that it will melt or 'fuse' when current over a certain value flows through it. In this way it serves as a protection for the generator against excessive currents, should a fault develop.

On many machines neither switch nor fuses are fitted. Since there is always some part of the external resistor connected permanently in the circuit of these machines, no damage can result from short circuits, and fuses are therefore unnecessary. The switch is also a matter of convenience and serves to isolate the machine from the electrode holder and work when required.

Interpoles, or commutation poles

Interpoles are small poles situated between the main poles of a generator and serve to prevent sparking at the brushes. The polarity of each interpole must be the same as that of the next main pole in the direction of rotation of the armature, as in Fig. 4.50*a*.

They carry the main armature current and, therefore, like the series winding on welding generators, are usually of heavy copper wire or strip.

They prevent distortion of the main flux, by the flux caused by the current flowing in the armature, and thus commutation is greatly assisted.

Most modern machines are fitted with interpoles, as they represent the

Fig. 4.49

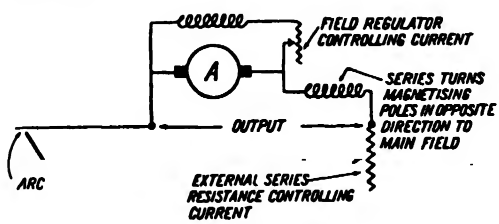
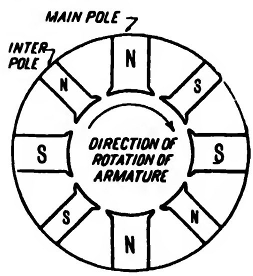


Fig. 4.50 (*a*)



most convenient and best method of obtaining sparkless commutation.

The following is a summary of the features of a good welding generator:

(1) Fine control of voltage.
(2) Fine control of current.
(3) Excitation must always provide a good welding voltage.
(4) Copper conductors of armature and field of ample size and robust construction, yet the generator must not be of excessive weight.
(5) Well-designed laminated magnetic circuit and accurate armature-pole shoe air gap.
(6) Good ventilation to ensure cool running.
(7) Well-designed ball or roller bearings of ample size and easily filled grease cups.
(8) Well-designed brush gear – no sparking at any load and long-life brushes.
(9) Bearings and brush gear easily accessible.
(10) Large, easily placed terminals enabling polarity to be quickly changed (or fitted with polarity changing switch).
(11) High efficiency, that is, high ratio of output to input energy. (60–65% efficiency is normal for a modern single-operator motor-driven direct current plant.)

Brushless alternators and generators

Brushless alternators and generators have no slip rings or commutators but use a rectifier mounted on the rotating unit (rotor) to supply direct current to excite the rotating field coils, the main current being generated in the stationary (stator) coils.

The rotor has two windings, an exciter winding and a main field winding. The exciter winding rotates in a field provided by exciter coils on the stator and generates a.c., which is passed into silicon diodes (printed circuit connected) mounted on the rotor shaft. The resultant d.c. passes through the rotating field coils of the main generator portion and the rotating field produced generates a.c. in the stationary windings of the main generator portion. If a d.c. output is required, as for welding purposes, this a.c. is fed into a silicon rectifier giving a d.c. output (Fig. 4.50*b*).

Current for the stator coils on the exciter is obtained from the rectifier supply and variation of the excitation current gives variable voltage control as on a normal generator, and residual magnetism causes the usual build-up.

Dual continuous control generator

In the dual continuous control generator, excitation current is supplied by the separate exciting generator shown on the left of Fig. 4.51*a*,

and the control of the excitation current is made by the field rheostat, which therefore controls the output voltage of the machine. Interpoles are fitted to prevent sparking and the continuously variable current control is in parallel with the differential series field, the current control being wound on a laminated iron core so as to give a smoothed output. This generator gives a good arc with excellent control over the whole range and is suitable for all classes of work.

Generators in parallel

The parallel operation of generators enables the full output of the machines to be fed to a single operator. If two shunt wound generators are

Fig. 4.50 (*b*)

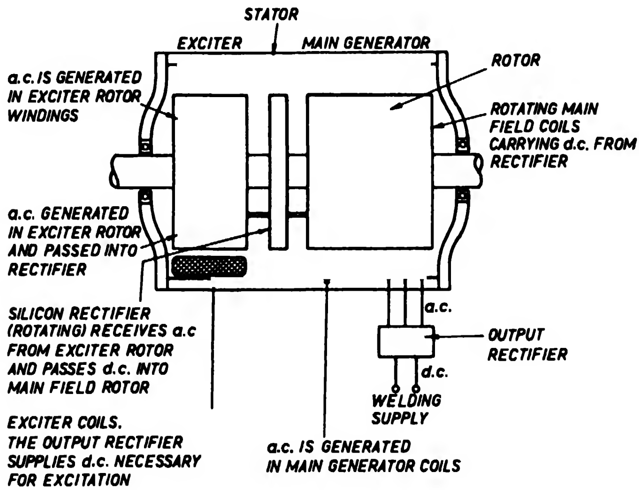
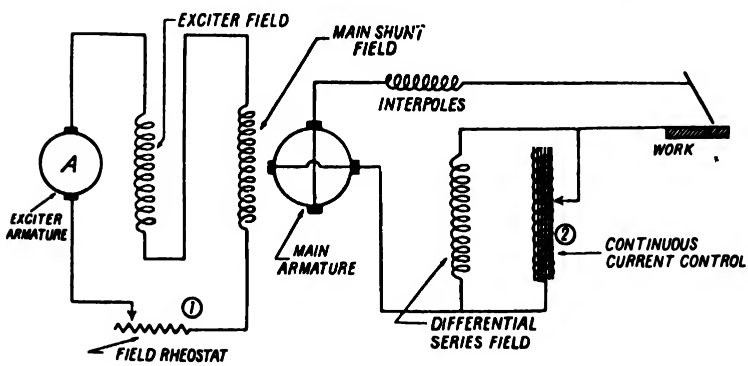
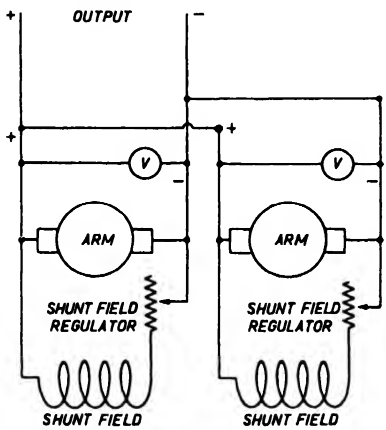


Fig. 4.51. (*a*) Welding generator with separate excitation. Regulation of controls (1) and (2) gives dual continuous control of voltage and current.

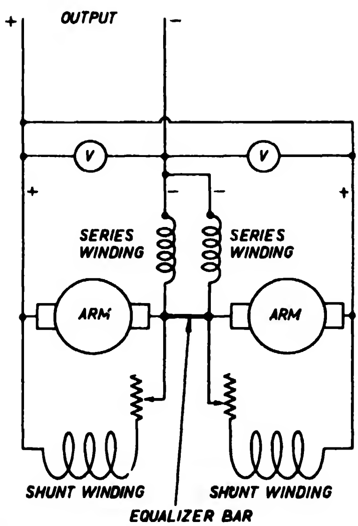


run up to speed and their voltages adjusted by means of the shunt field regulators to be equal, they can be connected in parallel by connecting + ve terminal to + ve, and − ve terminal to − ve, and the supply taken from the now common + ve and common − ve terminals. When a load is applied it can be apportioned between either machine by adjustment of the voltage. As the adjustment is made, for example, to increase the voltage of one machine this machine will take an increased share of the load and vice versa (Fig. 4.51*b*).

Fig. 4.51. (*b*) Shunt wound generators connected in parallel. (*c*) Compound wound generators connected in parallel.



(*b*)



(*c*)

Welding generators, however, are more often compound wound and if connected in parallel as for shunt machines they would not work satisfactorily, because circulating currents caused by any slight difference in voltage between the machines could cause reversal of one of the series fields, and this would lead eventually to one machine only carrying the load. If, however, an equalizer bar is connected from the end of the series field next to the brush connexion on each machine (Fig. 4.51*c*) the voltage across the series windings of each machine is stabilized and the machines will work satisfactorily. The equalizer connexion should be made when the machines are paralleled as for shunt machines, +ve to +ve and −ve to −ve, and load shared by operation of the shunt field regulators.

Static characteristics of welding power sources

Volt-ampere curves. Variation of the open-circuit voltage greatly affects the characteristics of the arc.

To obtain the volt-ampere curves of a power source:

(1) Set the voltage control to any value.
(2) With the arc circuit open, read the open-circuit voltage on the voltmeter.
(3) Short-circuit the arc.
(4) Vary the current from the lowest to highest value with the current control and, for each value of current, read the voltage. (Voltage will decrease as current increases.) Fig. 4.52*a*.

Plot a curve of these readings with voltage and current as axes. This curve is a volt-ampere curve and has a drooping characteristic. Any number of curves may be obtained by taking another value of open-circuit voltage and repeating the experiment. The curves in Fig. 4.52*b* are the results of typical experiments on a small welding generator.

Suppose Fig. 4.52*c* is a typical curve. When welding, the arc length is continually undergoing slight changes in length, since it is impossible for a welder to keep the arc length absolutely constant. This change in length results in a change in voltage drop across the arc; the shorter the arc the less the voltage drop. The volt-ampere curves shows us what effect this change

Fig. 4.52 (*a*)

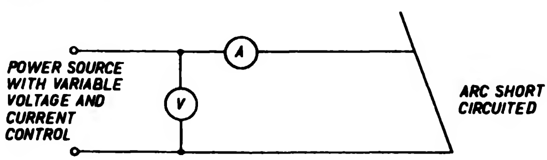


Fig. 4.52 (*b*)

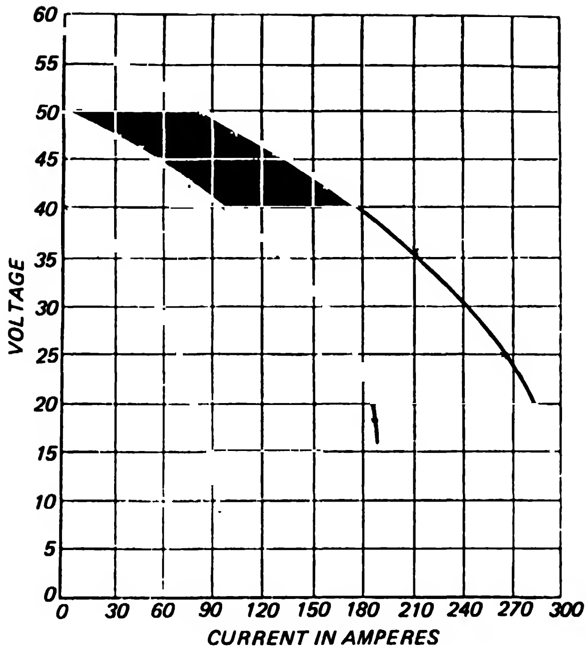
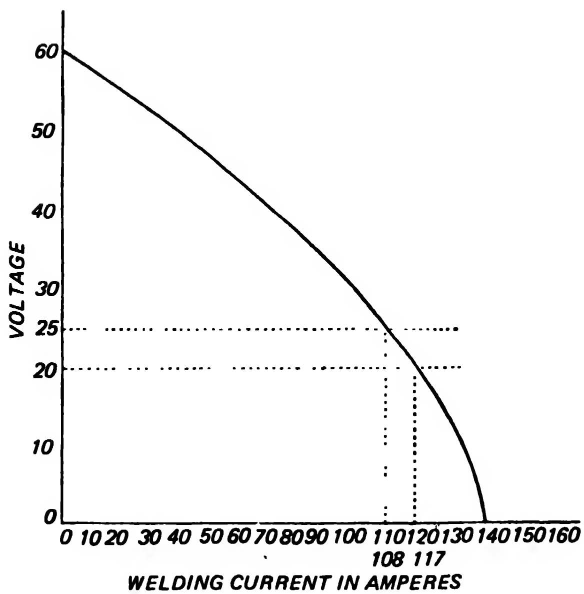


Fig. 4.52 (*c*)



of voltage drop across the arc will have on the current flowing. Suppose the arc is shortened and the drop changes from 25 to 20 V. From the curve, we see that the current now increases from 108 to 117 A.

The steeper the curve is where it cuts the arc voltage value, the less variation in current there will be, and, therefore, there will be no current 'surges' and the arc will be steady and the deposit even. Because the slope of the curve controls the variation of voltage with current this is known as 'slope control'. The dynamic characteristic of a power source indicates how quickly the current will rise when the source is short-circuited.

Variation of current and voltage control. Suppose a current of 100 A is suitable for a given welding operation. If the current control is now reduced, the current will fall below 100 A, but it can be brought back to 100 A by increasing the voltage control. The current control may be again reduced and the voltage raised again, bringing the current again to the same value. At each increase of voltage the volts drop across the arc is increased, so we obtain a different arc characteristic, yet with the same current.

This effect of control should be thoroughly grasped by the operator, since by variation of these controls the best arc conditions for any particular work are obtained.

The curves just considered are known as static characteristics. Now let us consider the characteristics of the set under working conditions; these are known as the dynamic characteristics, and they are best observed by means of a cathode-ray oscilloscope. By means of this instrument the instantaneous values of the current and voltage under any desired conditions can be obtained as a wave trace or graph, called an oscillograph.

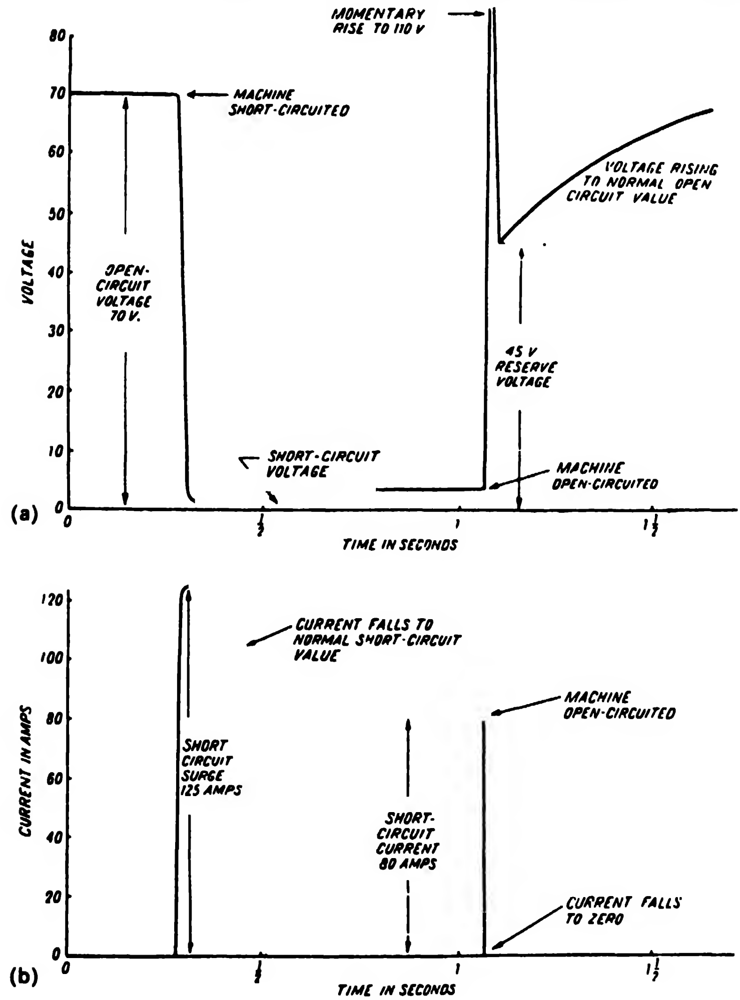
The curves drawn in Fig. 4.53 are taken from an oscillograph of the current and voltage variation on a welding power source when the external circuit was being short-circuited (as when the arc was struck) and then open-circuited again.

It will be noticed that the short-circuit surge of current (125 A) is about $1\frac{1}{2}$ times that of the normal short-circuit current (80 A). This prevents the electrode sticking to the work by an excessive flow of current when the arc is first struck, yet sufficient current flows initially to make striking easy. In addition, when the circuit is opened, the voltage rises to a maximum and then falls to a 'reserve' voltage value of 45 V and immediately begins to rise to normal. This reserve voltage ensures stability of the arc after the short-circuit which has occurred and makes welding easier, since short-circuits are taking place continually in the arc circuit as the molten drops of metal bridge the gap.

Motive power for welding generators

Welding generators may be motor- or engine-driven. Sets in semi-permanent positions, such as in workshops, are usually driven by direct current or alternating current motors, and these provide an excellent constant speed drive, since the speed is almost independent of the load. The motor and generator may be built into the same yoke, or may be separate machines. The first method is mostly used in modern machines, as much space is thereby saved.

Fig. 4.53
(*a*) Curve showing variation in voltage as machine is short-circuited and open-circuited.
(*b*) Curve showing variation of current due to above variation of voltage.



Motors of either type should be fitted with no-volt and overload tripping gear. The former automatically switches off the supply to the motor in the event of a failure of the supply and thus prevents the motor being started in the 'full on' position when the supply is resumed, while the latter protects the motor against excessive overloading, which might cause damage. This operates by switching the motor off when the current taken by the motor exceeds a certain value, which can be set according to the size of the motor.

Main switch and fuses usually complete the equipment of the motor. The motor-driven set may be mounted on wheels or on a solid bed, depending on whether it is required to be portable or not, and the equipment should be well earthed to prevent shock.

Portable sets for outdoor use are usually engine-driven, and this type of set is extremely useful, since it can be operated independently of any source of electric power. The engines may be of the petrol or diesel type and are usually the four-cylinder, heavy duty type with an adequate system of water cooling and a large fan.

A good reliable governor that will regulate the speed to very close limits is an essential feature of the engine. Many modern sets now have an idling device which cuts down the speed of the machine to a tick-over when the arc is broken for a period (which can be adjusted by the operator), sufficient for him to change electrodes and deslag. This results in a considerable saving in fuel and wear and tear and greatly increases the efficiency of the plant.

Direct drive is mostly favoured for welding generators. Belt drive is not very satisfactory, owing to the rapid application of the load when striking the arc causing slip and putting a great strain on the belt, especially at the fastener. V-belt drive sets, however, are used in certain circumstances.

Alternating current welding

Steel fabrication by manual metal arc welding using covered electrodes is now mainly performed using a.c. power sources and this method has certain advantages over the use of d.c. The chief of these are.

(1) The welding transformer (dealt with later) and its controller are very much cheaper than the d.c. set of the same capacity.

(2) There are no rotating parts, and thus no wear and tear and maintenance of plant.

(3) Troublesome magnetic fields causing arc blow are almost eliminated.

(4) The efficiency is slightly greater than for the d.c. welding set.

The following points should be noted concerning a.c. welding:

(1) Covered electrodes must be used. The a.c. arc cannot be used satisfactorily for bare wire or lightly coated rods as with the d.c. arc.

(2) A higher voltage is used than with d.c., consequently the risk of shock is much greater and in some cases, as for example in damp places or when the operator becomes hot and perspires, as in boiler work, a.c. welding can become definitely dangerous, unless care is taken.

(3) Welding of cast iron, bronze and aluminium cannot be done anything like as successfully as with d.c.

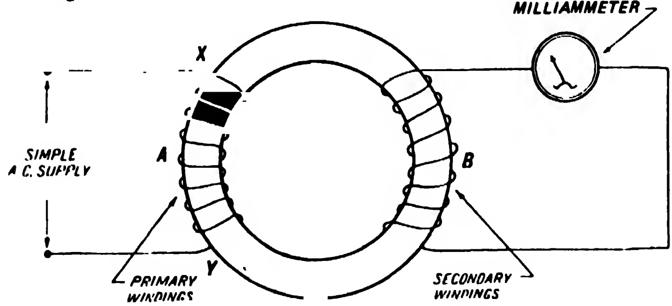
The transformer

The supply for arc welding with alternating current is usually from 80 to 100 V, and this may be obtained directly from the supply mains by means of a transformer, which is an instrument that transforms or changes the voltage from that of the mains supply to a voltage of 80 to 100 V suitable for welding. Since a transformer has no moving parts, it is termed a 'static' plant.

The action of the transformer can be understood most easily from the following simple experiment, first performed by Faraday.

An iron ring or core (Fig. 4.54) is wrapped with two *insulated* coils of wire: *A* (called the primary winding) is connected to a source of alternating current, while *B* (called the secondary winding) is connected to a milliammeter with a centre zero, which will indicate the direction of flow of the current in the circuit. With each revolution of the coil of the a.c. generator, the current flows in the primary first from *X* to *Y* and then from *Y* to *X*, and a magnetic flux is set up in the iron core which rises and falls very much in the same way as the hair spring of a watch. This rising and falling magnetic flux, producing a change of magnetic flux in the circuit,

Fig. 4.54



generates in the secondary coil an alternating current, the current flowing in one direction through the milliammeter when the current in the primary is from X to Y and then in the opposite direction when the current in the primary flows from Y to X. There is no electrical connexion between the two coils, but they are close coupled by being wound on the same iron core. A current generated in the secondary coil in this way, by a current in the primary, is said to be mutually induced, and the principle is that of *mutual induction*. Note that we again have the three factors necessary for generation as stated on p. 189: a conductor, a magnetic flux and motion. In this case, however, it is the change in magnetic flux which takes the place of the motion of the conductor, since this latter is now stationary.

Now let us wind a similar ring (Fig. 4.55) with 400 turns on the primary and 100 turns on the secondary, connect the primary to an alternating supply of 100 V, and connect a voltmeter across each circuit.

It will be found that the voltage across the secondary coil is now 25 V.

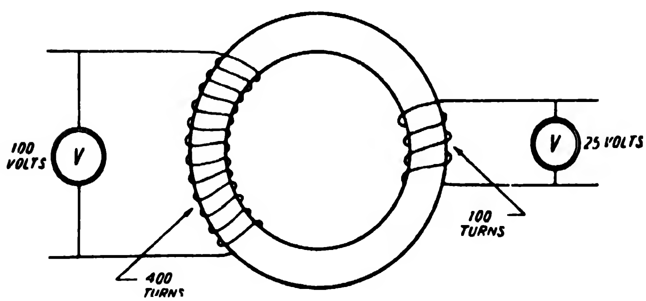
$$\text{Ratio of } \frac{\text{primary turns}}{\text{secondary turns}} = \frac{4}{1} \qquad \text{ratio of } \frac{\text{primary voltage}}{\text{secondary voltage}} = \frac{4}{1}.$$

Thus we see that the voltage has been changed in the ratio of the number of turns, or

$$\frac{\text{primary turns}}{\text{secondary turns}} = \frac{\text{primary volts}}{\text{secondary volts}}.$$

This is a simple transformer, and since it operates off one pair of a.c. supply conductors, it is called a *single-phase* transformer. The voltage supplied *to* the transformer is termed the input voltage, while that supplied *by* the transformer is termed the output voltage. If the output voltage is greater than the input voltage, it is termed a *step-up* transformer; while if

Fig. 4.55



the output voltage is less than the input, it is a *step-down* transformer. Transformers for welding purposes are always step-down, the output voltage being about 85 V. Single-operator transformers have two output tappings of 80 and 100 V, the higher voltage being suitable for light gauge sheet welding (Fig. 4.56). The input voltage to transformers is usually 415 or 240 V, these being the normal mains supply voltages. The alternating magnetic field due to the alternating current in the windings would generate currents in the iron core if it were solid. These currents, known as eddy currents (or Foucault currents), would rapidly heat up the core and overheat the transformer. To prevent this, the core is made up of soft iron laminations varnished with insulating varnish so as not to make electrical contact with each other, and clamped tightly together with bolts passing through insulating bushings to prevent the bolts carrying eddy currents. In this way losses are reduced and temperatures kept lower. Eddy currents are also used for induction heating in the electric induction furnace.

Since the power output cannot be greater than the input (actually it is always less because of losses in the transformer), it is evident that the current will be transformed in the opposite ratio to the voltage. For example, if the supply is 400 V and 50 A are flowing, then if the secondary output is 100 V, the current will be 200 A (Fig. 4.57).

Actually, the output current would be slightly lower than this, since the above assumes a 100% efficient transformer. A transformer on full load has an efficiency of about 97%, so the above may be taken as approximately true.

The highly magnetizable silicon iron core of the transformer is made up

Fig. 4.56

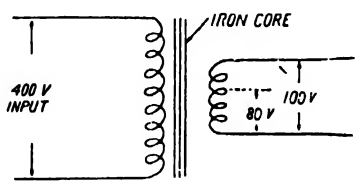
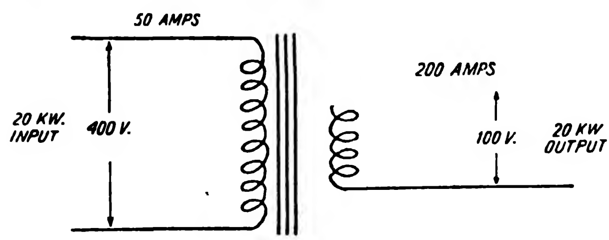


Fig. 4.57



of laminations bolted together and the coils fit over these (Fig. 4.58). It will be observed that the magnetic circuit is 'closed', that is, the flux does not have to traverse any air gap.

The single-operator welding transformer is made on this principle and is available in sizes up to 450–500 A.

The transformer may be of the dry type (air cooled) or it may be immersed in oil, contained in the outer container. Oil-immersed transformers have a lower permissible temperature rise than the dry type and, therefore, their overload capacity (the extent to which they may be used to supply welding currents in excess of those for which they are rated) is much smaller.

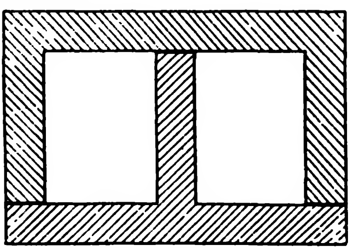
Excessive variation in the supply voltage to a transformer welding set may affect the welding operation by causing a variation in welding current and voltage drop across the arc and the open circuit voltage (OCV). For 80 V the ratio is 80/410. If the supply falls to 380 V the OCV of the secondary will now be 80/410 × 380 or approximately 76 V. This fall will reduce arc current by about 4 A if the original current was 100 A, and the arc voltage by 1–1.5 V, which will have some effect on welding conditions. Many modern welding units have thyristor regulators by which the arc voltage is kept constant irrespective of any variations of mains voltage, keeping welding conditions constant. Voltage control is by transductor, which gives infinite adjustment.

By law the supply authorities must not vary the supply voltage from that specified by more than 6% so that variation in the case of a specified 410 V supply is from 385–434 V, but this may be exceeded under adverse conditions. Small voltage variations have little effect on welding conditions.

Current control

Current control may be by tapped reactor (choke), flux leakage reactor, saturable reactor, leakage reactance moving coil, or thyristor

Fig 4.58



controlled transformer. In the latter the circuit is controlled by one knob and is stepless (see Thyristor).

Inductive reactor or choke

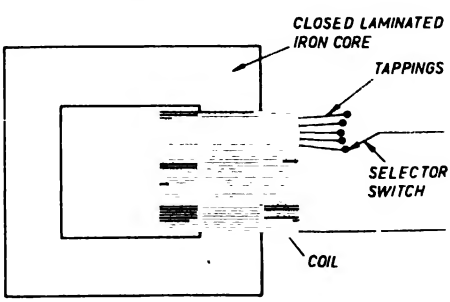
An inductive reactor or choke consists, in its simplest form, of a coil of insulated wire wound on a closed laminated iron core (Fig. 4.59). When an e.m.f. is applied to the coil and the current begins to flow, the iron core is magnetized. In establishing itself, this flux cuts the coil which is wound on the core and generates in it an e.m.f. in the opposite direction to the applied e.m.f. and known as the 'back e.m.f.'. It is the result of magnetic *self induction*, and its effect is to slow down the rate of rise of current in the circuit so that it does not rise to its maximum value as given by Ohm's law immediately the e.m.f. is applied; in a very inductive circuit the rise to maximum value may occupy several seconds.

The inductance of the circuit is proportional to the square of the number of turns of wire on the coil, so that increasing the number of turns greatly increases the inductive effect. When the current is fully established, there is energy stored in the magnetic circuit by virtue of the magnetic flux in the iron core. When the circuit is broken, the lines of force collapse, and in collapsing cut the coil and generate an e.m.f. in the opposite direction to that when the circuit was made, and which now tends to maintain the current in the original direction of flow. The energy of the magnetic flux is thus dissipated and may cause a spark to occur across the contacts where the circuit is being broken.

The direction of the induced e.m.f. in an inductive circuit is given by Lenz's law, which states: 'The direction of the induced effect in an inductive circuit always opposes the motion producing it.'

If an alternating current is flowing in the coil, the current will reverse before it has time to reach its maximum value in any given direction, and

Fig 4.59 Tapped choke



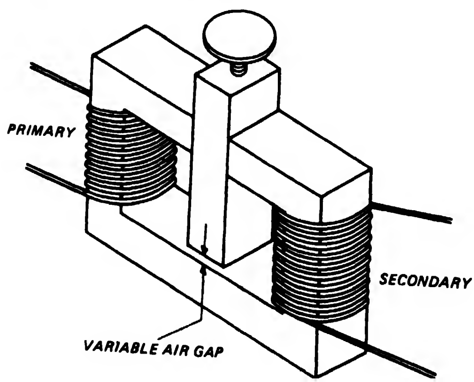
the more inductive the circuit the lower will the value of the current be, so that the effect is to 'choke' the alternating current. If the coil has tappings taken to a selector switch, the inductance of the circuit and hence the amount by which it can control or 'choke' the current can be varied (Fig. 4.59). Another method of varying the inductive effect is to vary the iron circuit so that the flux has a 'leakage path' other than that on which the coils are wound (Fig. 4.60), thus varying the strength of the magnetic flux in the core and hence the inductive effect.

The tapped reactor or choke is used to control the current in metal arc welding a.c. welding units. It can only be used on a.c. supplies and does not generate heat as does a resistor used for control of direct current. Any heat generated is partly due to the iron core, and partly due to the $I^2 R$ loss in the windings (Fig. 4.61).

Leakage reactance, moving coil current regulation

Stepless control of the current is achieved in this method by varying the separation of the primary and secondary coils of the transformer. The coils fit onto the iron circuit as shown in Fig. 4.62. The secondary coil supplying the welding current is fixed and the primary coil can be moved up and down by means of a screw thread and nut, operated by a winding handle mounted on top of the unit. As the primary coil is wound so as to approach the secondary coil the inductive reactance is reduced and the current is increased and vice versa, so that the highest current values are when the coils are in the closest proximity to each other. The moving coil carries a pointer which moves over two scales, one high current values and one low values, the different scales being obtained by two tappings on the secondary coil. The inductive reactance does not vary

Fig. 4.60. Flux leakage control.



directly with the separation of the coils, and current values get rapidly greater as the coils get near to each other.

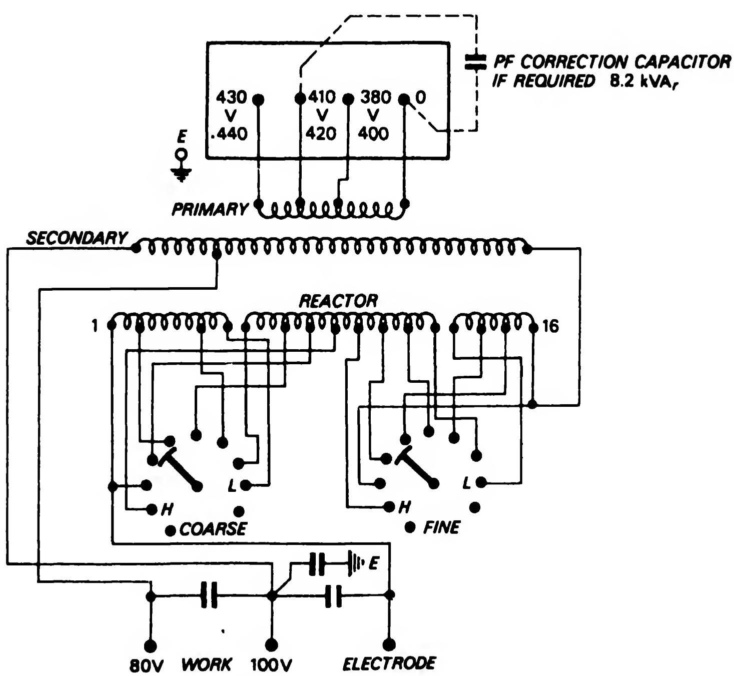
The merit of this method of current control is that there is no other item of equipment other than the transformer, thus reducing the initial cost, and there is stepless control operating with the simplest of mechanisms.

Magnetic induction and saturation

If a coil of insulated wire is wound on an iron (ferromagnetic) core and a current is passed through the coil, a magnetic flux is set up in the iron core. The strength of this flux depends upon the current in amperes and the number of turns of wire on the coil, that is, upon the ampere-turns (AT) so that the magnetizing force (**H**) is proportional to $A \times T$. If a graph is drawn between the magnetizing force and the flux density (**B**) in the core it is known as a **B**/**H** or magnetization curve (Fig. 4.63). It will be noticed that the flux density rises rapidly to X with small increases of **H** and then begins to flatten out until at Y further increases of **H** produce no further increase of flux density **B**. At the point Y the core is said to be magnetically saturated.

Use is made of this to control the current in power units, being known as the saturable reactor method.

Fig. 4.61

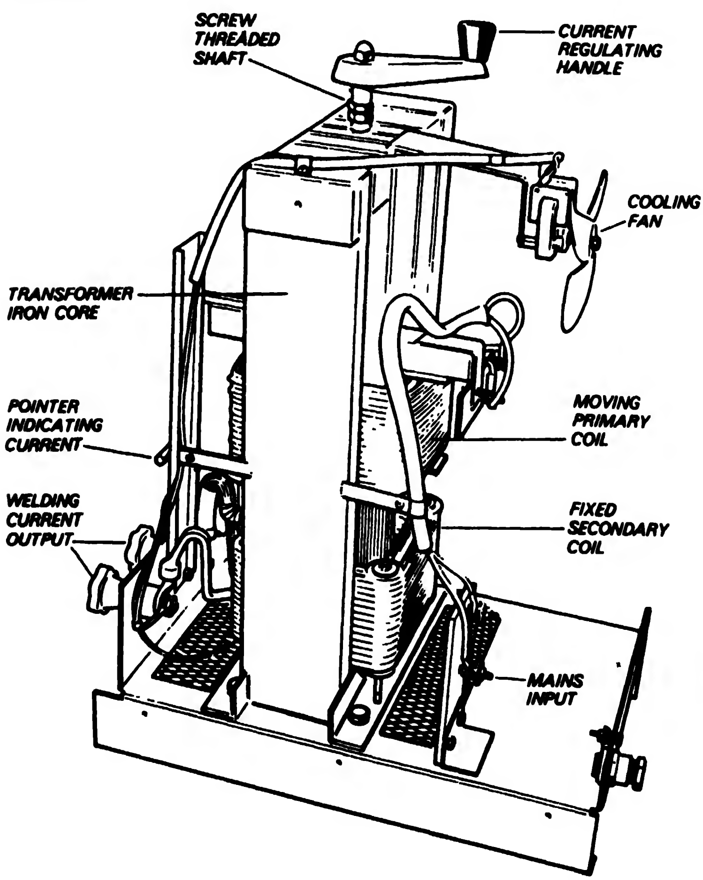


A coil A is wound on one limb of a closed laminated iron core and carries d.c. from a bridge connected rectifier X and controlled by a variable resistor Y (Fig. 4.64). A coil carrying the main welding current is wound on the other limb. When there is no current through A, the coil B will have maximum reactance because there is no flux in the core due to A and the welding current will be a minimum. As the current in A is increased by the control Y, magnetic saturation can be reached, at which point reactance is a minimum and the welding current will be a maximum represented by maximum voltage on V so that between these limits, accurate stepless control of the welding current is achieved.

Behaviour of a capacitor in an a.c. circuit

When a capacitor is connected to a d.c. source a current flows to

Fig. 4.62



charge it and no further current flows, the capacitor preventing or blocking the further flow of current.

If the capacitor is now connected to an a.c. source the change of polarity every half-cycle will produce the same change of polarity in the capacitor so that there is a flow of current, first making one plate positive and then half a cycle later making it negative, and the current which is flowing in the circuit, but not through the capacitor, is equal to the charge current. Hence a capacitor behaves as an infinitely high resistor in a d.c. circuit preventing flow of current after the initial charge, while in an a.c. circuit the current flows from plate to plate, not through the capacitor but around the remaining part of the circuit (Fig. 4.65).

Fig. 4.63

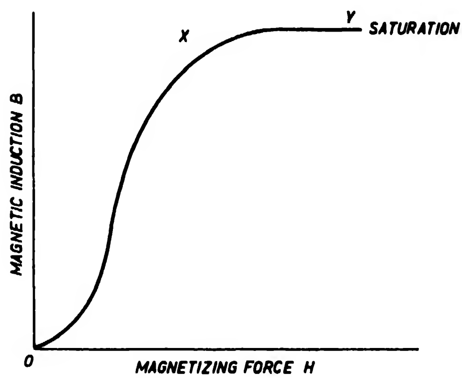
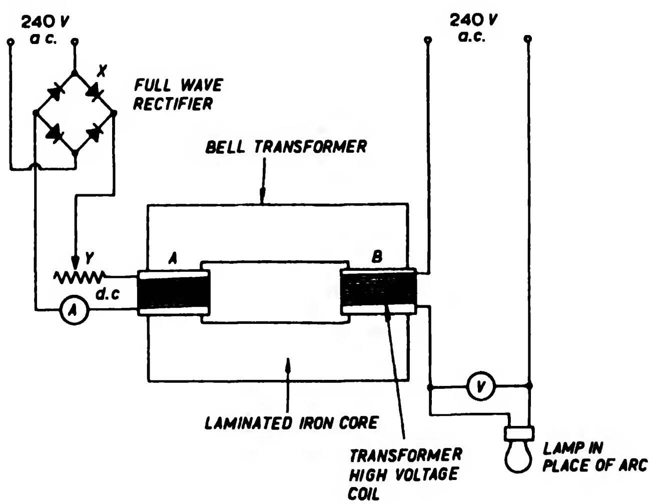


Fig. 4.64. Experiment with saturable reactor control.



Phase of current and voltage in an a.c. circuit

When a voltage is applied to a circuit and a current flows, if there is an inductive effect in the circuit the current will fall out of step with the voltage and lag behind it, rising and falling at the same frequency, but lagging a number of degrees behind. If there is capacitance in the circuit, the current will lead the voltage. Zero values of voltage and current do not occur together (Fig. 4.66*b*) and there is always some energy available, so that in a welding circuit the arc is easier to strike and maintain when a tapped reactor, for example, used for current control is in the circuit, since this produces an inductive effect.

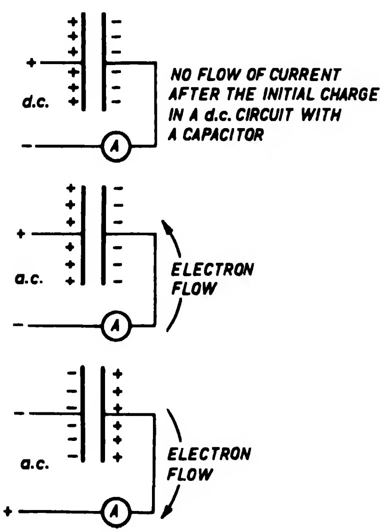
Inductive reactance

In any circuit, the effect of inductance is to increase the apparent resistance of the circuit. This effect is termed inductive reactance and if there is capacitance in the circuit the effect is known as capacitive reactance.

The unit of inductance is the henry (H). A circuit has an inductance of 1 henry if a current, varying at the rate of 1 ampere per second, induces an e.m.f. of 1 volt in the circuit.

If an alternating e.m.f. of V volts at frequency f Hz is applied to a circuit of inductance L henrys and a current of I amperes flows, the volts drop V across the inductor $= 2\pi LfI = IX_L$, where $X_L = 2\pi fL$. Comparing this with the volts drop V across a resistor R ohms carrying a current of I

Fig. 4.65. Flow of a.c. in a circuit containing a capacitor.



amperes, $V = I \times R$ so that X_L takes the place of R and is known as the inductive reactance.

Impedance

If a circuit contains resistance and inductance in series (Fig. 4.67*a*), the current I amperes flows through both inductance and resistance and there will be a volts drop IR across the resistor, in phase with the current, and a volts drop across the inductor, 90° out of phase with the current. This

Fig. 4.66 (*a*) Voltage and current in phase. Both pass through zero and maximum values at the same time. (*b*) Voltage and current out of phase due to inductance in circuit current lagging 45° behind voltage. Current and voltage now do not pass through zero and maximum values together

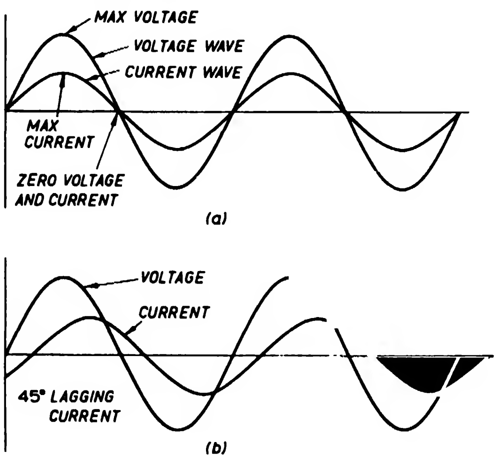
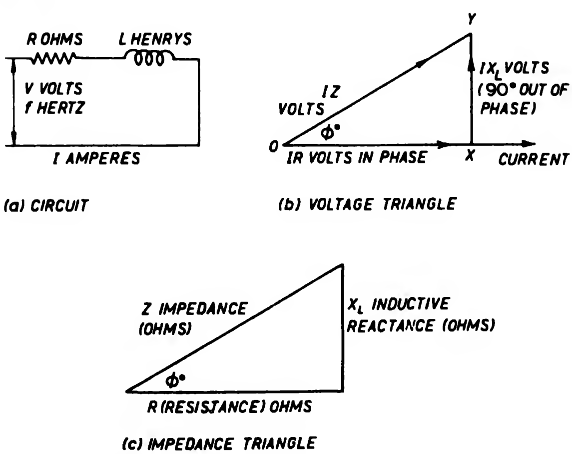


Fig. 4.67. Circuit with resistance and inductance in series.



can be represented by a phasor* diagram (Fig. 4.67*b*) using the current common to resistance and inductance as a reference phasor.

OX represents the volts drop IR in phase with the current.

XY represents the volts drop IX_L across the inductor, 90° out of phase, leading the current.

Then OY is the resultant voltage across the circuit, leading the current by an angle $\varphi°$ so that the current *lags* behind the voltage $\varphi°$, and if $OY = I \times Z$ where Z is the resultant effect of R and X_L, Z is termed the impedance. If the sides of the voltage triangle are all divided by I we have (Fig. 4.67*c*) the impedance triangle, and from this $Z^2 = R^2 + X_L{}^2$, or

$$\text{impedance}^2 = \text{resistance}^2 + \text{inductive reactance}^2.$$

The unit of capacitance is the farad (F), see p. 181. If an alternating e.m.f. of V volts at frequency f Hz is applied to a circuit of capacitance C farads and a current of I amperes flows:

$$V = \frac{I}{2\pi fC} = IX_C, \text{ where } X_C = \frac{1}{2\pi fC}$$

and is termed the capacitive reactance of the circuit.

Let a current of I amperes flow in a circuit containing a resistor of R ohms and a capacitor of capacitance C farads when an e.m.f. of V volts is applied at frequency f Hz (Fig. 4.68*a*). The voltage across the resistor, in phase with the current, is IR volts, whilst the volts drop across the capacitor is IX_C volts, the voltage lagging the current by 90°. The phasor diagram in Fig. 4.68*b* represents this with OX as the reference current phasor.

OX represents the volts drop IR, in phase with the current, XY represents the volts drop across the capacitor, lagging the current by 90°. Then OY represents the resultant voltage across the circuit, lagging the current by an angle $\varphi°$ and $OY = IZ$, where Z is the impedance of the circuit. Fig. 4.68*c* is the impedance triangle where $Z^2 = R^2 + X_C{}^2$. Impedance is measured in ohms (apparent).

* A scalar is a quantity which has magnitude only, e.g. mass or temperature. A vector is a quantity which has magnitude and direction, e.g. velocity or force. Phasors are rotating vectors. They are easier to draw than the more complicated wave form diagrams and are added or subtracted as are vectors.

In the phasor diagram the phasors are drawn to scale to represent the magnitude of the quantity (e.g. volts or amperes) and the angle between the phasors represents the phase displacement, the whole rotating counter-clockwise at an angular velocity measured in radians per second. Spokes on a bicycle wheel provide an analogy. Irrespective of the angular velocity of the wheel the angle between any two given spokes (representing the phasors) remains the same.

Resistance, inductance and capacitance in series

In a circuit such as that used for TIG welding there is inductance in the current controls, capacitance used for blocking the d.c. component, and the resistance of the circuit in series (Fig. 4.69*a*). The phasor diagram (Fig. 4.69*b*) shows that IX_L and IX_C are in opposite directions (anti-phase) and the resultant reactance is $X_L - X_C$, since inductance is usually larger than capacitance. It will be noticed that the impedance is always greater than the ohmic resistance so that, if d.c. is applied to a circuit designed for a.c., excess currents will flow. Fig. 4.69*c* is the voltage triangle and Fig. 4.69*d* the impedance triangle, and from this $Z^2 = R^2 + (X_L - X_C)^2$, or

$$\text{impedance} = \sqrt{[(\text{resistance})^2 + (\text{resultant reactance})^2]} \text{ ohms.}$$

Fig 4.68. Circuit with resistance and capacitance in series.

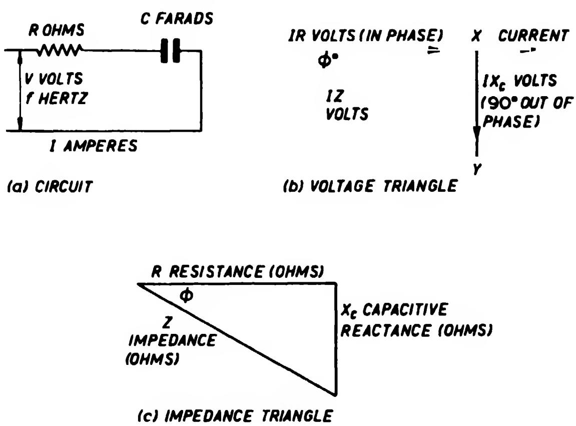
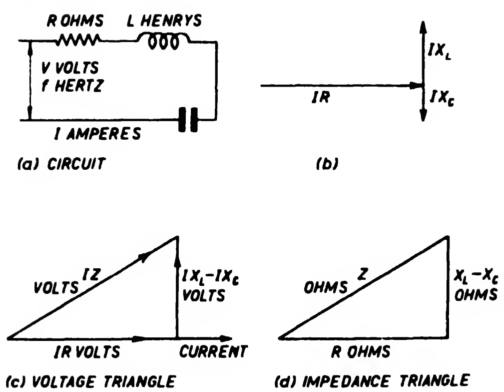


Fig. 4.69. Circuit with resistance, inductance and capacitance in series.



Power factor

Suppose that a current in a circuit is lagging by an angle φ° behind the voltage. To find the true power in the circuit the phasor diagram (Fig. 4.70*a*) is drawn, in which OV represents the voltage and OB the current lagging the voltage by an angle φ°. The length of OB is drawn to represent the current I in amperes and this is resolved into two components, AO in phase with the voltage and AB 90° out of phase with the voltage.

In the triangle AOB, $AO/OB = \cos\varphi$, therefore $AO = OB\cos\varphi$ and $AB = OC$ and $AB/OB = \sin\varphi$, therefore $AB = OB\sin\varphi$.

The component in phase with the voltage which is the power component is $I\cos\varphi$ amperes, while the component 90° out of phase (the reactive component) which is wattless is $I\sin\varphi$ and produces no useful power. Thus the power in a circuit which is the product of voltage and current is $VI\cos\varphi$. The cosine of any angle cannot be greater than 1, so that the power in a reactive circuit is always less than the product of the volts and amperes. If $\varphi = 0^\circ$, that is, the current and voltage are in phase, the power is $VI\cos 0^\circ = VI$, since $\cos 0^\circ = 1$. If $\varphi = 90^\circ$, the power is $VI\cos 90^\circ$, and since $\cos 90^\circ = 0$, the power is zero so that the reactive component produces no power in the circuit.

The factor $\cos\varphi$ is known as the *power factor*. The more inductive the circuit, the more will the current be out of phase with the voltage and the greater will be the angle φ so that $\cos\varphi$ gets smaller and the power becomes less.

If an a.c. welding supply is, for example, 40 V with a current of 120 A at a power factor of 0.7 lagging, the power in the circuit is

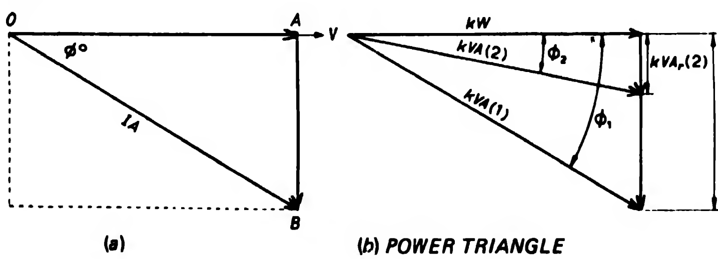
$$VI\cos\varphi = 40 \times 120 \times 0.7 = 3360\ \text{W} = 3.36\ \text{kW}.$$

If the power factor were unity or the circuit d.c. the power would be

$$40 \times 120 \times 1 = 4800\ \text{W} = 4.8\ \text{kW}.$$

Thus in any a.c. circuit, the product of the volts and amperes gives the apparent power in volt-amperes or kilovolt-amperes (kVA), while the true power in kilowatts is kVA × power factor $\cos\varphi$.

Fig. 4.70



If a power triangle is drawn, the kW are in phase with the voltage and the kVA are in phase with the current, and kVA_r represents the reactive component of the power.

In Fig. 4.70*b* the power triangle is drawn for two different angles of phase difference, φ_1 and φ_2, and the reactive components are kVA_r (1) and kVA_r (2) respectively, so that by reducing the angle of lag from φ_1 to φ_2, the reactive kVA is reduced from kVA_r (1) to kVA_r (2) and the total kVA is reduced from kVA (1) to kVA (2) whilst the true power is represented in each case by kW.

Since the kVA is proportional to the current flowing, the supply current can be reduced for a given kW by reducing the angle of lag φ, thus reducing the power (I^2R) loss in the supply cables and transformers.

To encourage consumers to have as high a power factor as possible by, for example, the installation of banks of capacitors, supply authorities have a tariff based on kVA_r maximum demand which must operate for a given period before registering on a dial and upon which maximum demand the tariff is based, so that a consumer with a low power factor and thus a high kVA_r pays more per unit for energy. Welding equipment, because of the transformers and chokes, tends to give a low power factor.

Fitting of power factor improvement capacitors is an important consideration especially when there is a large transformer load as in the welding industry. Capacitors for power factor improvement are rated in kVA_r, the *r* indicating the reactive (out of phase) component of the power. For example, suppose a typical transformer has a maximum output welding current of 450 A with an input of 440 V, 90 A and a lagging power factor of 0.46 (current lagging behind the voltage by 62°). If an 8.2 kVA_r bank of capacitors is installed. the input current will now fall to 75 A at 440 V, improving the power factor to 0.57 (lagging 55°). In terms of power, the original input was approximately 40 kVA, but with the capacitors improving the power factor the new power input has been reduced to 33 kVA, giving a considerable reduction in power consumed. Thus the saving in energy cost would soon pay for the capital outlay of the power factor improvement capacitors (Fig. 4.71).

Three-phase welding supply

For convenience in transmission and distribution, alternating current is supplied on the 'three-phase' system. The alternators have three sets of coils set at an angle of 120° to each other, instead of only one coil as on the simple alternator which we considered. These coils can be connected, as shown in Fig. 4.72, and the centre point, termed the star point, is where the beginning of each coil is connected, and the wire from

Fig. 4.71

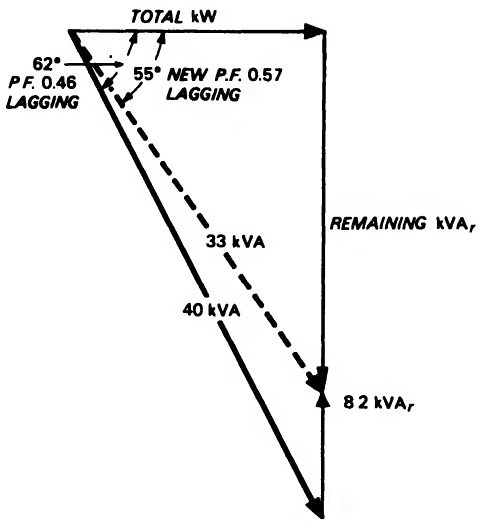
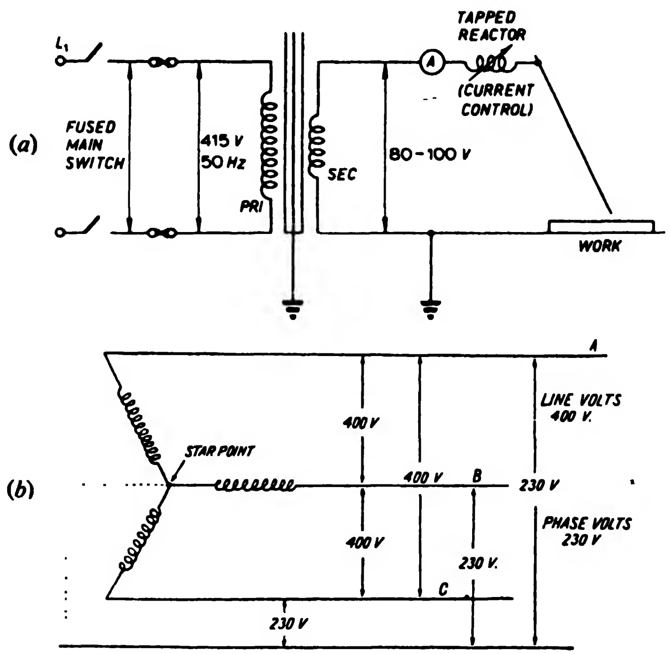


Fig. 4.72. (*a*) Connexions of a simple single-phase single-operator transformer set. (*b*) three-phase, four-wire system.



this point is termed the neutral. *A*, *B* and *C* are the lines. The voltage between *A* and *B*, *B* and *C*, *C* and *A* is termed the line voltage and is usually for supply purposes between 440 and 400 V. The voltage between any one of the lines and the neutral wire, termed the phase voltage, is only $1/\sqrt{3}$ of the line voltage, that is, if the line voltage is 400 V the voltage between line and neutral is $400/\sqrt{3} = 230$ V, or if the line voltage is 415 V the phase to neutral voltage is 240 V.

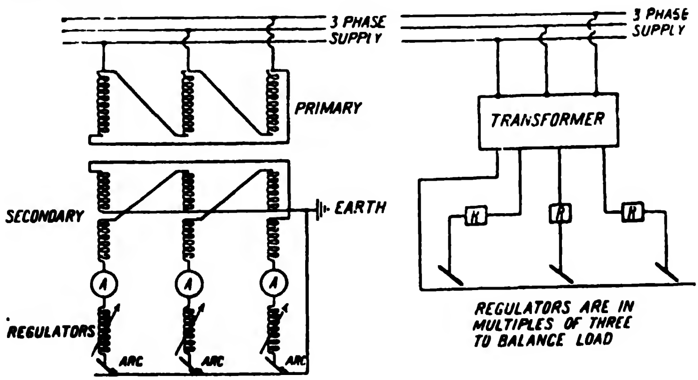
Welding supplies for more than one welder are supplied by multi-operator sets from the above type of mains supply.

Welding transformers

Welding transformers can be single-phase or three-phase. Single-phase transformers are connected either across two lines with input voltage 380–440 V or across one line and neutral when the voltage is 220–250 V. Evidently the single-phase transformer is an unbalanced load since all three lines are not involved. To balance the load equally on the three lines is not possible in welding using three single-phase transformers (Fig. 4.73*a*) since the welders are seldom all welding together and using the same current, so that in practice balance is never realized. Three-phase transformers on the other hand give a better balancing of the load even when only one welder is operating (Fig. 4.73*b*). Single-phase transformers are available for single-operator welding with a variety of outputs. As the input voltage is reduced the input current rises for the same power output so that it is usually the smaller output units which are made for line-to-neutral (240 V) connexion. Larger units are connected across two lines to keep the input current down.

The open circuit voltage (OCV) depends upon the particular transformer. Many transformers have 80 to 100 OCV selected as required, for example giving 50–450 A at 80 OCV and 60–375 A at 100 OCV. Other

Fig. 4.73 (*a*)



transformers may have a lower OCV of 70 V or even 50 V. The electrode classification indicates the types of electrode coverings suitable for the various OCV, and the striking voltage required is always given with the instructions for use of a particular type of electrode.

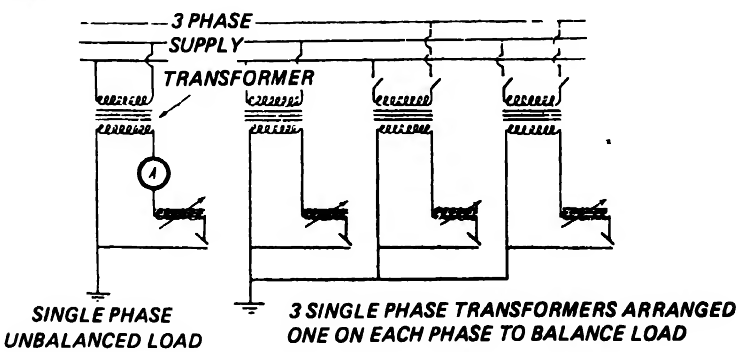
Smaller transformers with output currents of about 200 A maximum are air-convection-current cooled: larger units are forced draught (fan assisted) while most of the largest units are oil cooled.

As is the case with most electrical machines the duty cycle is important in order to keep the temperature rise within permissible limits. Although the maximum current specified for a given transformer may be say 200 A, this rating may be only possible for a 25% duty cycle, with, for example, 180 A at 30% and 100 A at 100% duty cycle (continuous welding). When choosing a unit therefore it is important to estimate the average current settings that will be used and the approximate duty cycle, so that a large enough unit can be selected, i.e., one that will perform the work without excessive temperature rise.

Current control can be by tapped choke, leakage reactance moving coil, thyristor, and for fine current settings can have 40–50 steps with two selectors, one coarse, one fine, while the leakage reactance moving coil type can have a continuously variable current control operated by hand wheel or lever.

When transformer units are to be used for TIG welding in conjunction with an HF unit they are fitted with an HF protection circuit because of the high voltage involved. Multi-operator equipment is often used in larger welding establishments at a saving in capital cost, with 6, 8 or 12 welders being supplied from one three-phase transformer, each with his own current regulator. The sizes vary from those for 6 welders each with a maximum welding current of 350 A to the largest units for 12 welders with a maximum current of 450 A each and a rating of 486 kVA (Fig. 4.74).

Fig. 4.73 (*b*)



When using a transformer in which the current is selected by a coarse and fine tapping switch, the current should not be altered whilst the welding current is flowing since the arcing which occurs as the selector passes from stud to stud damages the smooth surface of the contact stud. If the transformer is oil cooled, the quenching action of the oil prevents serious arcing, but some oil may be carbonized and this will eventually cause a deterioration of its insulating qualities.

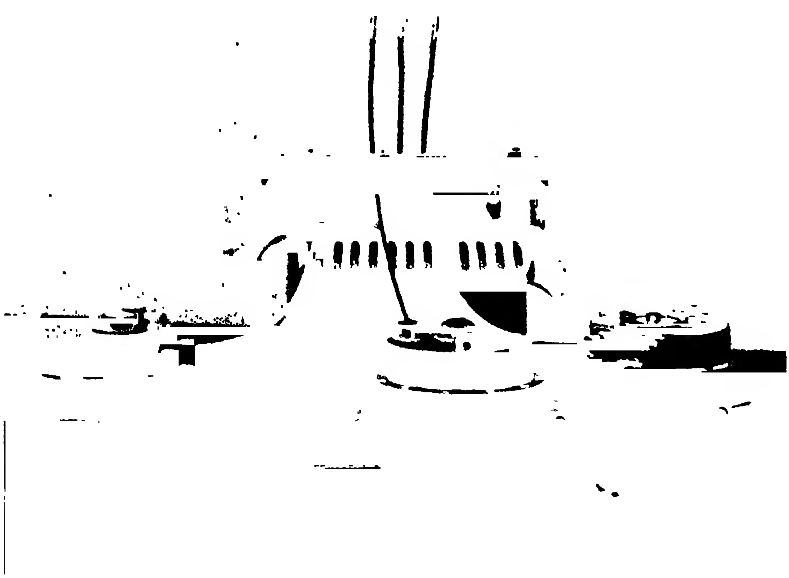
In addition, the three-phase transformer is cheaper to manufacture and install than three single-phase transformers and, because of this, is often found wherever many welders have to be supplied, as in shipyards and engineering works. Each welder has his own current regulator, as in the single-phase set, but it is not mobile as is the single-operator set. Details of the electrical equipment used in TIG, MIG and CO_2 processes are included under their respective headings.

Note. See also BS 638, *Arc welding plant, equipment and accessories.*

Parallel operation of welding transformers

Welding transformers of similar type can be connected in parallel to give a greater current output than could be provided by either of them used singly. The transformers should have their primaries connected across the same pair of lines and the output welding voltages should be the same in order to prevent circulating currents flowing in the secondary windings

Fig. 4.74. Three-operator set, showing the single three-phase transformer and three welding regulators.



before they are connected to a load. There is no problem of phase rotation but the output should be checked for 'polarity'.

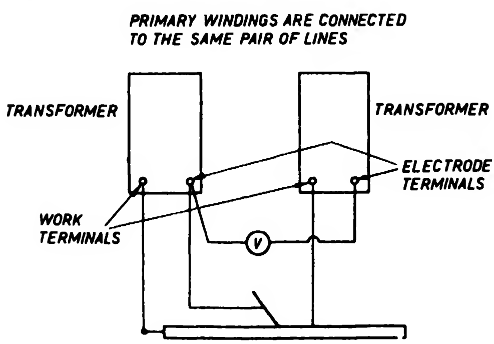
This is done by connecting both 'work' terminals together and placing a voltmeter across the 'electrode' terminals as shown in Fig. 4.75. If the voltmeter reads zero the transformers have similar polarity and the electrode terminals can be connected together, and welding performed from the paralleled units. If the voltmeter reads twice the normal output voltage the polarity is reversed and the connexions to one pair of secondary terminals (work and electrode) should be reversed, when the test should show zero voltage and the transformers can now be paralleled.

Earthing

If a person touches a 'live' or electrified metal conductor, a current will flow from this conductor, through the body to earth, since the conductor is at higher electrical pressure (or potential) than the earth. The shock that will be felt will depend upon how much current passes through the body and this in turn depends upon (1) the voltage of the conductor, (2) the resistance of the human body, (3) the contact resistance between body and earth.

The resistance of the human body varies considerably and may range from 8000 to 100 000 ohms, while the contact resistance between body and earth also has a wide range. Resistance to earth is high if a person is standing on a dry wooden floor and thus a low current would pass through the body if a live conductor is touched, while if a person is standing on a wet concrete floor and touches a live conductor with wet hands the resistance to earth is greatly lowered, a larger current would pass through the body and consequently a greater shock would be felt. It may be stated here that care

Fig. 4.75. Paralleling of welding transformers, polarity test.



should be taken to avoid shock when welding in damp situations, especially with a.c. The operator can wear gloves and thus avoid touching the welding terminals with bare hands and he can stand on dry boards.

Most electrical apparatus, such as motors, switch gear, cables, etc., is mounted in, or surrounded by, a metal casing, and if this should come into contact, through any cause whatever, with the live conductors inside, it will then become electrified and a source of danger to any one touching it.

To prevent this danger, *all* metal parts of electrical apparatus *must* be 'earthed', that is, must be connected with the general mass of the earth so that at all times there will be an immediate and safe discharge of energy. Good connexion to earth is essential. If the connexion is poor, its resistance is high and a current may follow an easier alternative path to earth through the human body if the live metal part is touched.

For earthing of electrical installations in houses, the copper pipes of the cold water system are sometimes satisfactory since they are sufficient to carry to earth currents likely to be met with in this type of load.

Connexion from the 'earthing system', as it is termed, to earth is made in various ways. Earth plates of cast iron or copper, 1–1.5 m square and buried 1.5–2 m deep, are in general use in this country. They are surrounded by coke and the area around is copiously watered. Tubes, pipes, rods and strips of copper driven deep into the ground are used both in this country and in the USA and the area round them is frequently covered with common salt and again copiously watered.

It is evident that the 'earthing system' must be continuous throughout its length and must connect up and make good contact with every piece of metal likely to come into contact with live conductors. In factories and workshops the cables are carried in steel conduits and this forms the earthing system, the conduit making good contact with all the apparatus which it connects. Any metal part which may become live discharges to earth, through the continuous steel tubing system. To ensure that connexion to earth is well made, extra wires of copper with terminal lugs attached are connected from the conduit to the metal parts of apparatus such as motors and switch gear and ensure a good 'bond' in case of poor connexion developing between the conduit and the metal casing of the apparatus. In the case of portable apparatus such as welding transformers, regulators, welding dynamos (motor driven), drills, hand lamps, etc., an extra earthing wire is run (sometimes included in the flexible tough rubber supply cable) and makes good connexion from the metal parts of the portable apparatus to the main earthing system.

When steel wire or steel-tape armoured cable is used, the wire or tape is utilized as the earthing system. In all cases extra wires are run whenever

necessary to ensure good continuity with earth, and the whole continuous system is then well connected to the earth plate by copper cables.

In a.c. welding from a transformer it is usual to earth one of the welding supply terminals in addition to the metal parts of the transformer and regulator tanks. This protects the welder in the event of a breakdown in the transformer causing the mains supply pressure to come into contact with the welding supply.

Low voltage safety device

As we have seen, if a welder is working in a damp situation or otherwise making good electrical contact through his clothes or boots with the work being welded (as for example inside a boiler or pressure vessel) and he touches a bare portion of the electrode holder or uses bare hands to place an electrode in the holder, his body is making contact across the open circuit voltage of the supply.

If this is d.c. at about 50–60 OCV practically no effect is felt but if the supply is from a transformer at say 80 OCV, this is the rms value and the peak of this is about 113 V so that the welder will feel an electric shock, its severity depending upon how good a contact is being made between electrode and work by the welders body. In some cases the shock can be severe enough to produce a serious effect.

A safety device is available which is attached to the transformer welding unit and consists of a step-down transformer and rectifier giving 25 V d.c. with contactors and controls.

When the transformer is switched on, a d.c. voltage of 25 V appears across electrode holder and work terminals. When the electrode is struck on the work and the circuit completed a contactor closes and the 80 OCV of the transformer appears between electrode and work and the arc is struck. Immediately the arc is extinguished the 25 V d.c. reappears across electrode and work terminals thus giving complete safety to the welder. Green and red lights indicate low volts and welding in progress respectively.

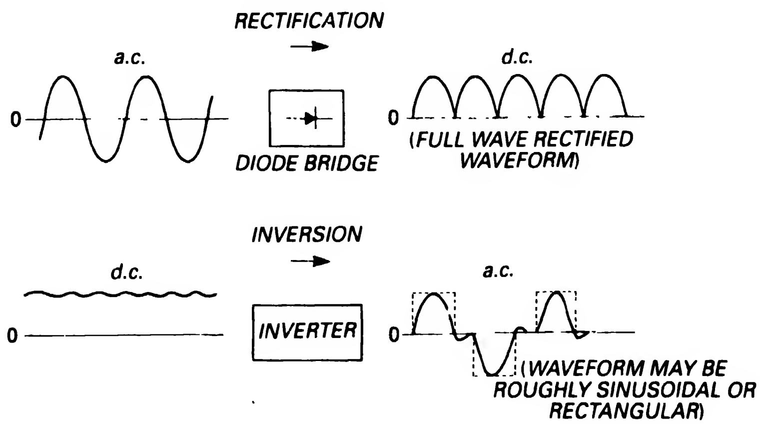
5

The inverter

Inversion is the opposite of rectification (Fig. 5.1). Rectification is the conversion of alternating current into direct current and is achieved using rectifiers or diodes (described on pp. 199–203): four diodes in bridge connection for single phase and six diodes for three-phase input (shown in Fig. 4.44*b*, *c*). Inversion converts direct current into alternating current. An inverter is not simply a device like a diode, but a network of many components designed to achieve this conversion (Fig. 5.2).

The great majority of arc welding today uses direct current, and since the mains are invariably alternating current, some method is required for changing from a.c. to d.c. Inversion is only part of what happens within the inverter power source. Many other electronic and electrical conversions and transformations are required to convert the mains supply

Fig. 5.1. Rectification and inversion principles



into one suitable for welding. Figs. 5.3 *a*, *b* and *c* illustrate a typical power source, transformer and inductor of the inverter type, together with one of similar output but of non-inverter design. There is a great reduction in size and weight (and hence portability) resulting from the inverter-based design. There are other advantages discussed later but size and weight are the most obvious.

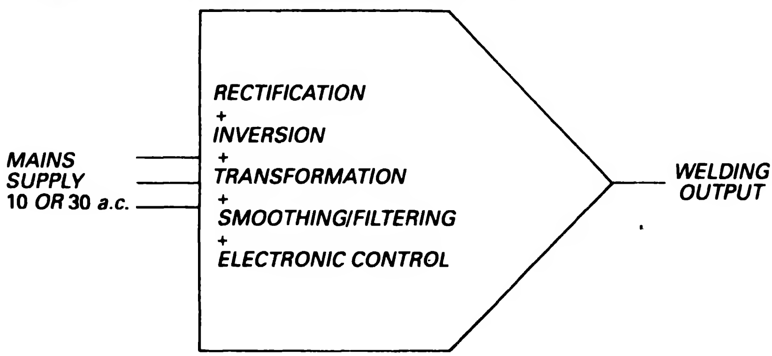
Transformer and inductor

In a transformer there are two separate coils (primary and secondary), or windings, wound on a laminated iron core, the laminations being coated with insulating varnish; the bolts or rivets fastening the laminations together are mounted on insulating sleeves to decrease the circulating eddy currents further. Any change of current in the primary coil produces a change of magnetic flux in the core and this change of flux generates an induced current in the secondary coil by 'mutual induction'. The ratio of the voltage V_p applied to the primary to the voltage V_s induced in the secondary equals the ratio of the number of turns N_p on the primary to the number of turns N_s on the secondary, thus

$$\frac{V_p}{V_s} = \frac{N_p}{N_s},$$

the coils being close coupled (Fig. 5.4). Note that a change of flux occurs when there is a change in the primary current, e.g. at make or break in a d.c. supply or in an a.c. applied to the primary. Any a.c. applied to the primary induces an a.c. in the secondary since the flux in the core is continuously changing.*

Fig. 5.2. Electrical operations within an inverter source



* Note that the efficiency of a transformer increases with the load, being over 90% at full load

Fig. 5.3 (*a*) 300 A 60% duty inverter and conventional power source.

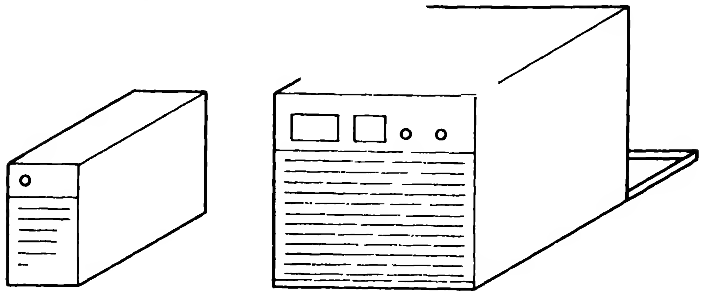


Fig. 5.3. (*b*) 3-phase 50 Hz transformer compared with inverter transformer at 25 kHz

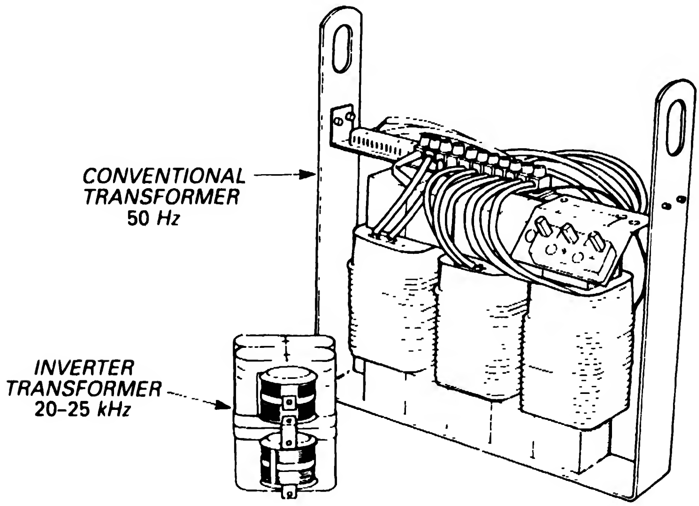
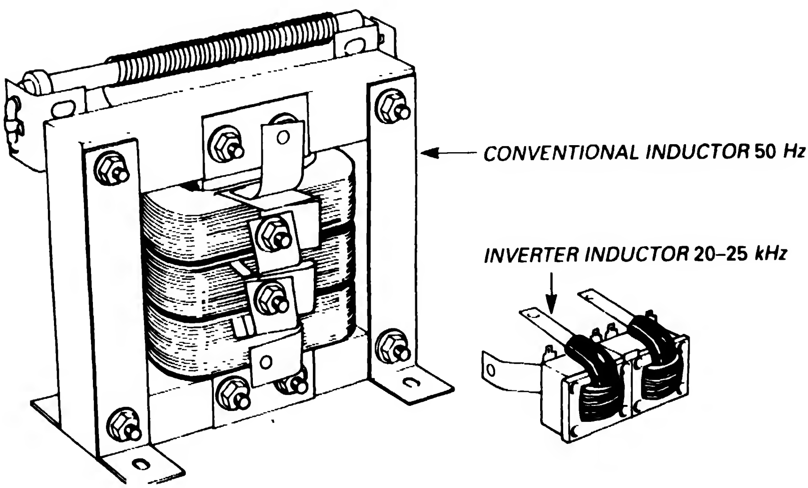


Fig 5.3 (*c*) Smoothing reactor or inductor for 50 Hz and 25 kHz compared.



Losses in the transformer

(1) Copper loss (dissipated as heat), caused by the ohmic resistance of the coil due to the current flowing in it. It can be reduced by using high conductivity copper and by reducing the number of turns where possible.

(2) Iron loss (also dissipated as heat), caused by circulating currents induced in the iron core, giving (*a*) power (I^2R) loss and (*b*) loss due to hysteresis (see pp. 249–51). To reduce these losses, the laminations are varnished and thus electrically insulated from each other and are made of highly magnetizable, low hysteresis iron. Above 5 kHz the core is usually made of sintered iron granules known as ferrite, which greatly reduces loss in the core (see also pp. 219–24 and Fig. 4.64).

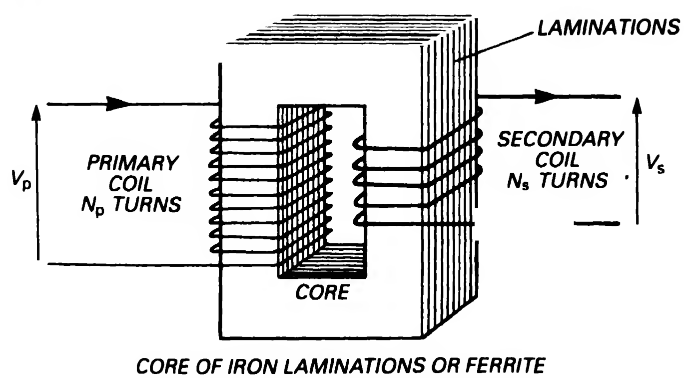
The voltage generated in the secondary coil depends partly upon the flux density:

$$V = 4.44 \times (\text{flux density}) \times (\text{area of cross-section}) \times (\text{frequency } f) \times N_s$$

Since the flux density is limited because of the magnetizability of the core, then for a constant input voltage an increase in f will allow either a reduction in area of cross-section of the core or a reduction in the number of turns N_s, or both, so that increasing f results in a much lighter transformer.

The d.c. reactor consists of a coil, which will carry the heavy currents used in welding, wound on a laminated core. Any change of current in this one-coil reactor generates a back e.m.f. in the coil (Lenz's law) due to self-induction in the coil. Because of this back e.m.f. the forward flowing current is smoothed by the reactor (hence the name, smoothing reactor). Again an increase in frequency allows a much smaller inductor and energy

Fig. 5.4 A basic transformer: $V_p/V_s = N_p/N_s$.



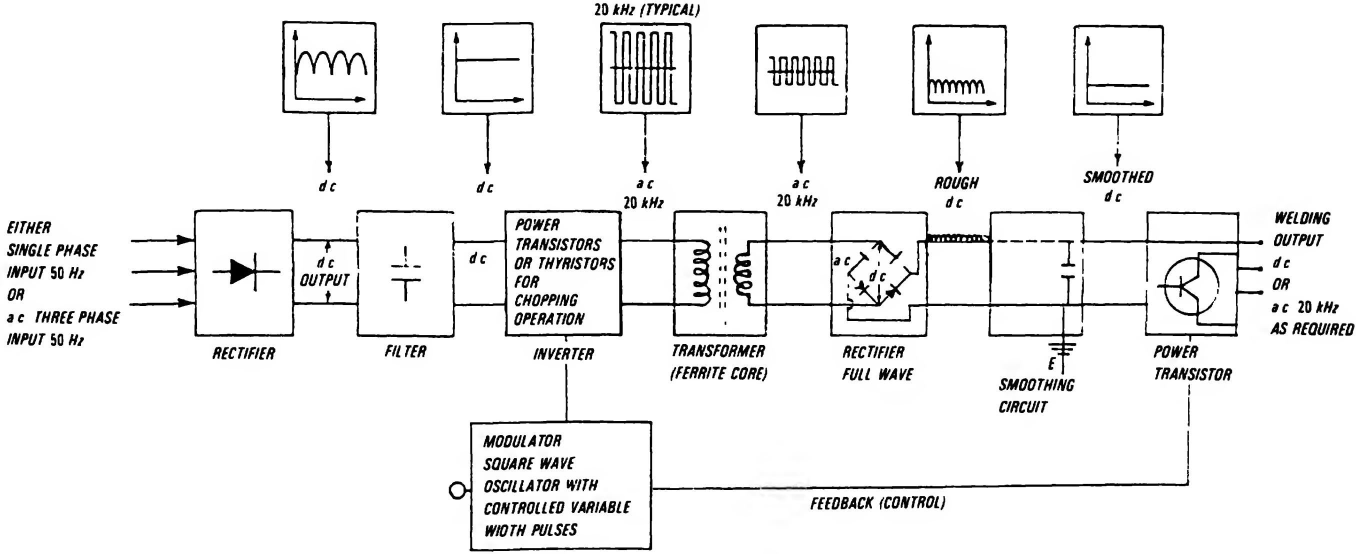


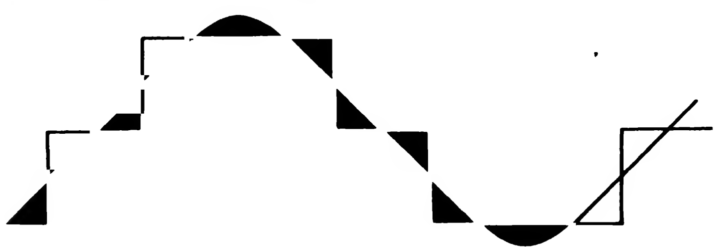
Fig 5 5 Block diagram of basic inverter circuit single-phase or three-phase (see also pp 203 and 205).

savings in the smaller winding (Fig. 5.4). Incoming mains are supplied at 50 Hz frequency. If this were increased to 10000 Hz (10 kHz) then, in theory, the transformer and reactor core would be reduced some 200 times. There are additional advantages to reducing the size and weight of the unit. Since the length of both primary and secondary turns would be reduced, the copper loss would be reduced so that the power source would be more efficient. An increased frequency has a marked effect upon the inductance since the control circuits adapt and modify the output proportionally faster. Increasing the frequency from 50 Hz to 50000 Hz would theoretically produce a speed of response 1000 times faster.

Inverter design and operation

The inverter is an electronic network for converting d.c. to a.c. and the frequency of the current must be increased from that of the 50 Hz mains to up to 50 kHz. We have seen that increasing the frequency gives more controllable and adjustable qualities since it is easier to change electronic circuits than to vary large inductances made of iron and copper. The inverter circuit (Fig. 5.5) shows the layout of the various instruments which are all contained within the framework of the inverter power source. First the incoming mains are passed into a rectifier (single or three-phase) which converts the a.c. to d.c. In order to improve the power factor (pp. 232–3) of the power source a large filter capacitor immediately follows the rectifier stage. This has the advantage of providing a fast response energy store (the mains supply is relatively slow). Then the inverter circuit converts the incoming d.c. obtained from mains frequency to square wave a.c. again (Fig. 5.6) but at a much higher frequency than that of the mains supply, and usually within the range 5–50 kHz. This a.c. at high frequency is passed into a transformer bringing down the voltage and increasing the current to that used in a welding circuit. It is again rectified to d.c. and is passed through the filter inductor where, by Lenz's

Fig. 5.6. Square wave and sine wave.



law, it is smoothed before passing to the welding terminals for connection to the electrode, or TIG torch.

Many units today have a d.c. or a.c. (HF) output (Fig. 5.5). This type of power source may have back-to-back or push–pull connection of more than one inverter, but the arrangement shown in Fig. 5.7 is perhaps the simplest and most common. The d.c. welding output is connected to a network of four high-current semi-conductor switches (thyristors or transistors) in a 'bridge network'. The switches are switched on and off in pairs, 1 and 3 together, or 2 and 4 together, by a timing circuit. The output is a.c. (HF), the current square wave, suitable for welding aluminium, and this network is a further form of inversion. Fig. 5.8 shows an average filter network while Fig. 5.7 shows d.c. to a.c. conversion with alternate firing thyristors.

Control systems in inverters

In order to obtain a greatly increased frequency, the square wave in the inverter has to be 'chopped' up into a series of pulses. This is performed by the 'chopper' circuit. Pulses of variable width are fed into the inductor/filter network at a fixed frequency. The greater the width of

Fig 5.7. d.c. to a.c conversion of welding output.

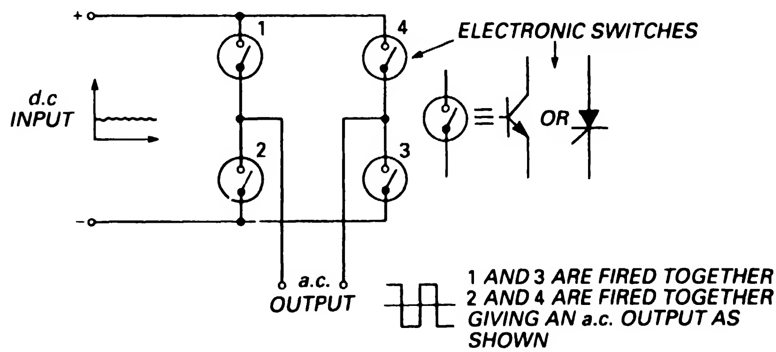
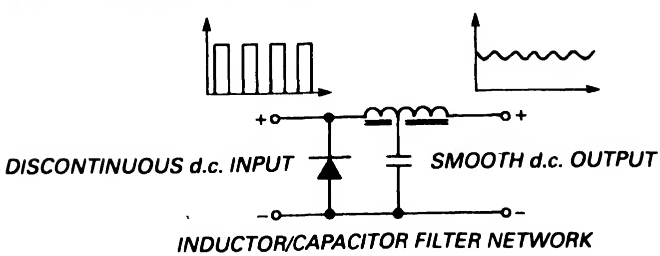


Fig. 5.8. Averaging/filtering network



the pulses the higher the average energy supplied per second and the greater the average d.c. output. This method is termed *pulse width modulation* (PWM) and is the method most commonly used in inverters today.

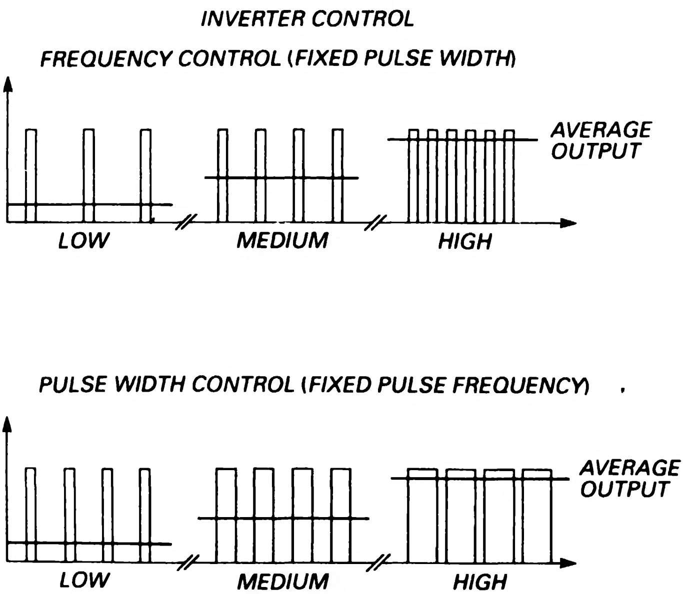
The other method termed *frequency modulation* uses pulses of constant width which are fed into the inductor/filter network. Depending upon the frequency of the supply pulses, the average output is higher or lower: the more pulses per second the more energy delivered per second, and the higher the average output (Fig. 5.9).

The use of electronic feedback control is now standard in these power sources. Sensing devices (shunts, etc.) in the welding circuit measure both welding current and voltage. Signals from these sensors are fed back to the control electronics (usually printed circuit boards), which compare the values measured with those required, as set on the operator controls. Electronic signals are then generated either to increase or to decrease the pulse width or the inverter frequency.

This type of 'closed loop' or feedback system continuously corrects output for any change in mains supply and welding conditions, and enables the accurate setting of welding parameters (Fig. 5.10).

Depending upon whether the information fed back from the welding output is primarily current or voltage, the power source can easily be

Fig 5.9. Frequency and pulse width control.



adapted for MMA and MIG (drooping characteristic). By combining both current and voltage feedback, sources with varying volt–ampere slope can be readily achieved. Additionally, various dynamic properties, including the ability to pulse for pulsed MIG welding, can be incorporated.

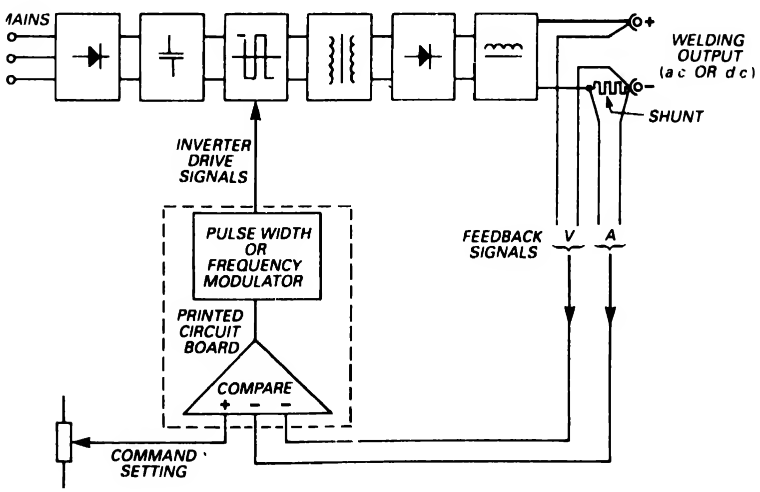
Remember that at this greatly increased frequency, changes in arc conditions and changes in instructions are responded to extremely quickly.

Although many inverter power sources utilize so-called hard electronics, with the function of the circuit dependent upon the exact circuit details (resistors, capacitors, transistors, etc.), several newer designs use microprocessor-based control systems. Such new machines are 'software controlled' offering even greater flexibility, and commonly include computer-type keypad programming systems with digital display of welding parameters. Fig. 5.11 shows an example of a 500 A multiprocess inverter-based power source using microprocessor control.

Iron loss

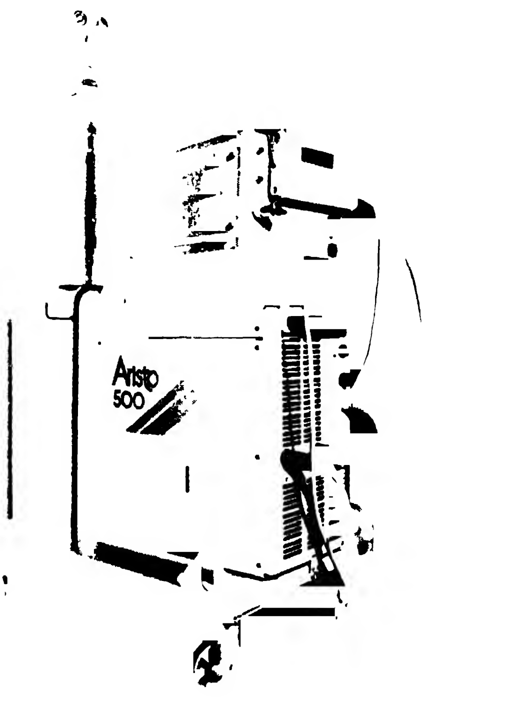
In a magnetic cycle, the flux density B varies with the magnetizing field H. Fig. 5.12 shows the variation of the magnetizing force and the flux density induced when a sample of steel goes through a complete cycle, known as the hysteresis loop. The area of the loop is indicative of the iron loss: the larger the area, the greater the loss. Note that the first part of the

Fig. 5.10. Feedback control system used in inverters.



curve (broken line) is traversed once only, when the core is being magnetized for the first time. After this there is always some residual magnetism in the core (Fig. 5.12). The magnetic flux lags behind the magnetizing force, hence the name hysteresis. To reduce these losses, the core is made of iron laminations, which help to prevent circulating currents in the highly magnetizable low hysteresis iron. Above a frequency

Fig. 5.11. A modern machine using the inverter principle for MMA, MIG and TIG welding with microcomputer control. Memory allows up to 100 different welding programs to be stored. The method (consumable and/or shielding gas) can be programmed, and the unit automatically selects the welding parameters best suited for each application. Input 414 V 30A; max output 500 A at 60% duty cycle, 400 A at 100% duty cycle. Settings: MMA and air gouging 8 500 A, MIG/MAG 40–500 A, TIG 8 500 A. OCV 65. Power factor 0.97. Lift arc starting for TIG welding. Mains voltage fluctuation 10%. Wire feed and arc voltage synergically controlled. Four-wheel drive for wire feed. Water- or air-cooled torches. Synergic settings for MIG, pulsed MIG and MMA welding. Wire feed speed 0.22 m/min. Steel diameters 0.8 2.4 mm; stainless diameters 0.8–1.6 mm; aluminium diameters 1.0 2.4 mm; cored wires diameters 0.9–3.2 mm. Weight 72 kg.

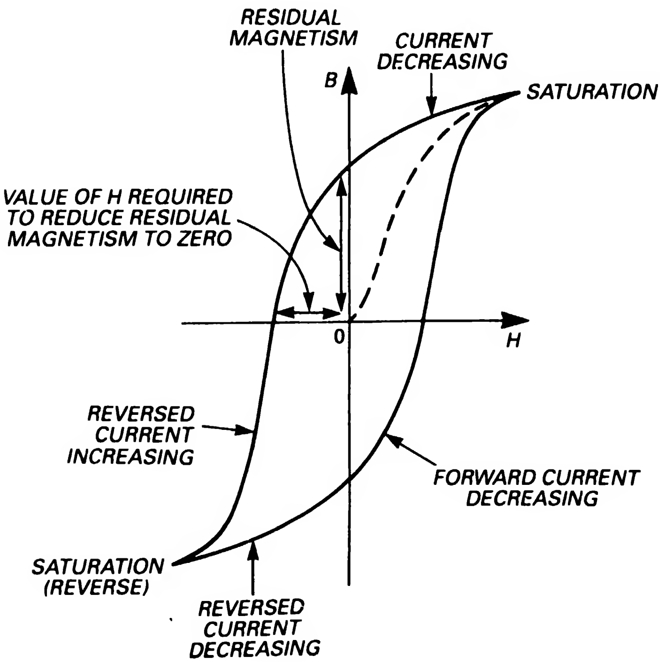


of about 5 kHz the core is made of sintered iron granules, greatly reducing the iron loss and the weight of the transformer. The inductor, which has one coil only, has copper and iron losses similar to those of the transformer.

Summary

In an inverter-based welding power supply the incoming mains supply at 50 Hz frequency is first rectified to d.c. before being fed to the inverter circuit. This circuit then reconverts the d.c. supply to an a.c. supply but at a much higher frequency than that of the mains with ranges of 5 50 kHz (usually an average of 20 25 kHz). Since the mains transformer is now operating at a high frequency, its size and weight are greatly reduced compared with that required at 50 Hz. The high-frequency transformers use cores of ferrite, not iron laminations, and after transformation to the correct voltage and current levels, the high-frequency a.c. is again rectified to d.c. and supplied to a welding output smoothing filter inductor, the size and weight of which is also reduced because of the high frequency. Machines offering d.c. and a.c. output

Fig. 5 12. Hysteresis.



generally incorporate an inverter/commutator circuit immediately before the output terminals (Fig. 5.7). The a.c. (HF) output is usually used for aluminium welding.

Inverters use either frequency modulation or pulse width modulation (PWM) as the means of control (Fig. 5.9). Current and voltage feedback signals from the welding output are used within the closed-loop control systems to maintain the required welding parameters. By varying the electronic control system, or software in the case of microprocessor-based controls, it is possible to provide machines with variable static and dynamic characteristics for a wide range of welding processes (MMA, TIG, MIG/MAG pulsed MIG etc.).

Inverters are characterized by their small size and low weight compared with conventional machines and offer high efficiency and high power factor; their flexibility, fast response and excellent welding properties will extend their use over the coming years.

6

Inspection and testing of welds

The following British Standards apply to this chapter:

BS 6072 *Method for penetrant flaw detection*
BS 6443 *Method for magnetic particle flaw detection*
BS 2600 *Radiographic examination of fusion welded butt joints in steel*
BS 2901 *Radiographic examination of fusion welded circumferential butt joints in steel pipes*
BS 709 *Methods of destructive testing fusion welded joints and weld metal in steel*
BS 3923 *Methods for ultrasonic examination of welds.* Parts 1 and 2
BS 3451 *Methods of testing fusion welds in aluminium and aluminium alloys*
BS 4206 *Methods of testing fusion welds in copper and copper alloys*

See also BS 3863 *Glossary of terms used in non-destructive testing*

During the process of welding, faults of various types may creep in. Some, such as those dealing with the quality and hardness of the weld metal, are subjects for the chemist and research worker, while others may be due to lack of skill and knowledge of the welder. These, of course, can be overcome by correct training (both theoretical and practical) of the operator.

In order that factors such as fatigue may not affect the work of a skilled welder, it is evidently necessary to have means of inspection and testing of welds, so as to indicate the quality, strength and properties of the joint being made.

Visual inspection, both while the weld is in progress and afterwards, will give an excellent idea of the probable strength of the weld, after some experience has been obtained.

Inspection during welding

Metal arc welding. The chief items to be observed are: (1) rate of burning of rod and progress of weld; (2) amount of penetration and fusion; (3) the way the weld metal is flowing (no slag inclusions); (4) sound of the arc, indicating correct current and voltage for the particular work.

Oxy-acetylene welding. The chief items are: (1) correct flame for the work on hand; (2) correct angle of blowpipe and rod, depending on method used; (3) depth of fusion and amount of penetration; (4) rate of progress along the joint.

The above observations are a good indication to anyone with experience what quality of weld is being made, and this method furnishes one of the best ways of observing the progress of welders when undergoing training.

Inspection after welding

Examination of a weld on completion will indicate many of the following points:

(1) Has correct fusion been obtained between weld metal and parent metal?

(2) Is there any indentation, denoting undercutting along the line where the weld joins the parent metal (line of fusion)?

(3) Has penetration been obtained right through the joint, indicated by the weld metal appearing through the bottom of the V or U on a single V or U joint?

(4) Has the joint been built up on its upper side (reinforced), or has the weld a concave side on its face, denoting lack of metal and thus weakness?

(5) Does the metal look of a close texture or full of pinholes and burnt?

(6) Has spatter occurred, indicating too high a current or too high a voltage across the arc or too long an arc?

(7) Are the dimensions of the weld correct, tested, for example, by gauges such as shown in Fig. 6.1?

A study of the above will indicate to an experienced welder what faults, if any, exist in the work and then provide a rapid and useful method of ensuring that the right technique of welding is being followed.

A very useful multi-purpose pocket-size welding gauge has been designed by the Welding Institute. It is of stainless steel and enables the following measurements to be taken in either metric or Imperial units: material thickness up to 20 mm; preparation angle 0 60°; excess weld metal

capping size; depth of undercut and of pitting; electrode diameter; fillet weld throat size and leg length and high–low misalignment.

Visual inspection, however, has several drawbacks. Take, for example, the double V joint shown in Fig. 6.2. It will obviously be impossible to observe by visual means whether penetration has occurred at the bottom of the V except at the two ends.

A great variety of methods of testing welds are now available and, for convenience, we can divide them into two classes: (1) non-destructive, (2) destructive.

Destructive tests are usually carried out either on test specimens made specially for the purpose, or may even be made on one specimen taken as representative of several similar ones.

Destructive tests are of greatest value in determining the ultimate strength of a weld and afford a check on the quality of weld metal and skill of the operator. (Visual inspection obviously falls under the heading of non-destructive tests.)

Non-destructive tests (NDT)

(1) Penetrant fluid and visual inspection.
(2) Magnetic (*a*) magnetic particle, (*b*) search coil.
(3) X-ray.
(4) Gamma-ray.
(5) Ultrasonic.
(6) Application of load.

Fig. 6.1 Weld test gauges.

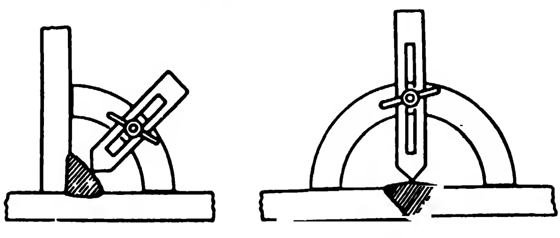
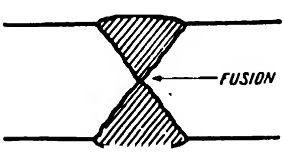


Fig. 6.2



Penetrant fluid. The surface is cleaned and the dye penetrant fluid is painted or sprayed on the area to be examined. The fluid is allowed to penetrate into any defects such as cracks and crevices and the surplus is removed. A developer powder is sprayed on to the surface and soaks up the penetrant leaving a stain indicating the defect. The surface can also be viewed under ultraviolet light in darkened conditions, when the fluorescent penetrant glows, indicating the crack.

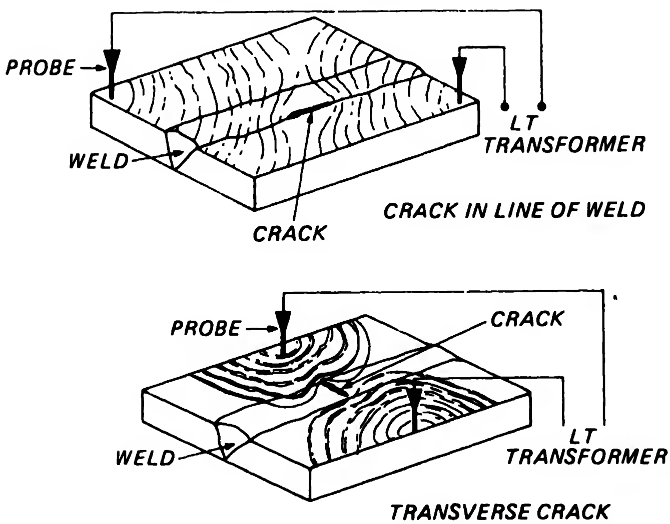
Surface scratches may mask the result and penetrant contamination of the crack occurs but the method is used as an addition to X-ray or gamma-ray inspection.

Magnetic tests for magnetizable specimens. Surface defects only.

(*a*) The specimen under test is magnetized using a low voltage transformer and two probes for making contact with the specimen, and to enable the flux to be varied in the specimen. Iron filings in a finely divided or colloidal state are applied as an ink or as a powder and the flux is distorted at the crack or other fault with magnetic poles being formed. Probe positions will give a flux either with the weld or across it as shown in Fig. 6.3. Examination can also be performed with ultraviolet light and fluorescent ink.

(*b*) The specimen is magnetized as before and search coils, connected to a galvanometer which measures small currents, are moved over the specimen. If a crack exists in the specimen, the change of magnetic flux across it will cause a change in the current in the

Fig. 6.3. Position of probes showing magnetic flux



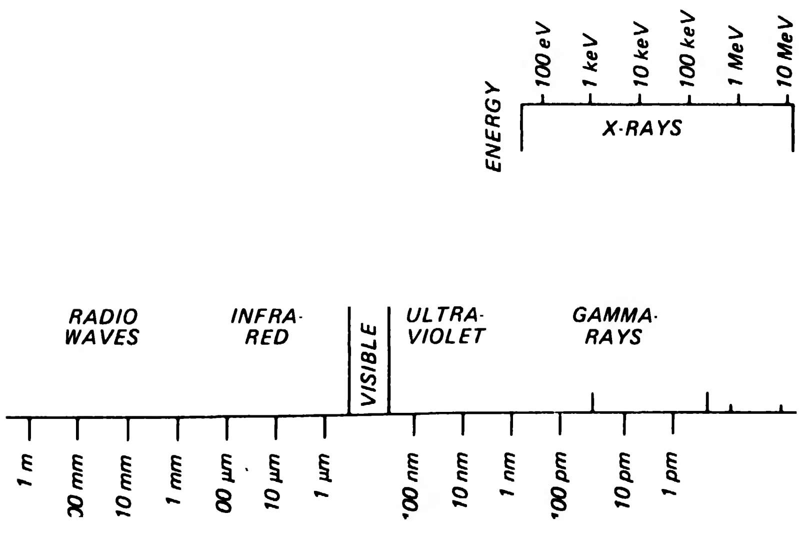
search coil and is indicated by fluctuations in the galvanometer needle. This method has advantages over method (*a*) in that the surface need not be machined and that defects just below the surface are indicated.

X-rays and gamma rays

X-rays are an electromagnetic radiation delivered in 'quanta' or parcels of energy as opposed to continuous delivery. They move at the speed of light in straight lines; are invisible; are not deviated by a lens; ionize or liberate electrons from matter through which they can pass and they destroy living cells. They are generated by an X-ray tube, described later.

Gamma-rays are similar to X-rays but differ in wavelength, X-rays having a continuous or broad spectrum while gamma-rays are made up of isolated wavelengths and have a line spectrum depending upon the element used. Iridium, for example, has two distinct types of atoms, one with a mass number of 191 and the other with a mass number of 193. The latter has two extra neutrons in its nucleus. These are written 191 Ir and 193 Ir and are isotopes of iridium. If the stable isotope is bombarded with neutrons in a nuclear reactor (such as at Harwell) an additional neutron is induced into the nucleus and the isotope becomes unstable and is termed a radioactive isotope or radioisotope. These unstable isotopes suffer radioactive decay or change into the stable form over a period of time and the type of radiation (wavelength) and the period of time for which it is given out determines its

Fig. 6.4 Electromagnetic spectrum showing position of X-rays and gamma-rays.



suitability for a particular use. Some isotopes emit radiation at a single level; for example cobalt-60 emits at two energy levels near each other. Others emit a broader spectrum comparable with that from an X-ray tube. Iridium-192 has 16 differing energy levels and gives better contrast with specimens of varying thickness comparable with that of an X-ray distribution.

Fig. 6.4 shows the wavelengths of e.m. radiations (spectra) given in metres (m); micrometres, ($1 \mu m = \frac{1}{1000}$ mm); nanometres ($1\ nm = \frac{1}{1000}\ \mu m$) (1 Å (ångström) $= \frac{1}{10}$ nm).

Radioactive decay, in which the isotope emits radiation to attain the stable state, may vary from a fraction of a second to hundreds of years. The decay rate cannot be speeded up nor slowed down and obeys an exponential law, being proportional to the number of radioactive nucleii so that complete decay never occurs as some radioactive nucleii are always left. For this reason decay of a radioactive isotope is expressed in terms of its half life, which is the period of time for the number of nucleii to decay to half that number. Those chosen for radiographic testing of welded joints may vary from a few weeks (e.g. thulium-170) to some years (e.g. cobalt-60). The table gives the radioactive isotopes in general use for testing welds.

The unit of radioactivity is the curie (Ci), also millicurie (mCi) and microcurie (μCi). This is the amount of radioactive material in which 3.7×10^{10} disintegrations take place per second.

The röntgen (named after the German physicist 1845–1923) is the unit of radiation. It is the amount of X-ray or gamma-ray radiation which produces ions carrying one e.s. unit of either sign in one cubic centimetre of dry air at STP.

The rad (radiation absorption dose) is the unit of absorbed dose and is the energy imparted to matter by an ionizing radiation. It is equivalent to 0.01 joule/kg or 6.242×10^{10} MeV per kilogram of irradiated material. An exposure of 1 röntgen will produce an absorbed dose of 0.869 rad in air.

Characteristics of gamma-ray sources used in gamma-radiography

Source	Material thickness mm: Steel	Material thickness mm: Light alloys	Half life	Gamma energies MeV	Exposure rate (R/h) (for 1 Ci equivalent activity at 1 m)
cobalt-60	50 0 150 0	150 0–450.0	5 27 years	1.730·1.333	1.3000
iridium-192	12.5 62 5	40.0 190.0	74.00 days	0.206 0.612	0 4800
thulium-170	2 5 12 5	7 5 37 5	128.00 days	0.052:0.084	0.0025
ytterbium-169	2 5 15 0	7 5 45.0	32.00 days	0 008 0.308	0 1250

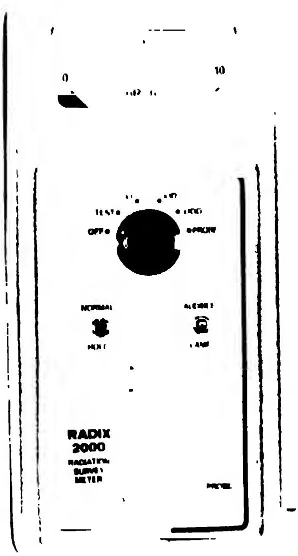
The rem (röntgen equivalent man) expresses the biological effect of radiation on the human body and is measured in J/kg.

A radiation survey meter with a Geiger–Muller tube detecting the radiation (Fig. 6.5) enables the radioactivity level to be indicated at any point in mR/h. It has a probe connexion socket and may be fitted with an audible warning. Other adjustable types give a red-light and audible warning when the radiation exceeds a given value of say 5 mR/h.

Only trained and radiation-classified personnel are allowed to operate X-ray and gamma-ray equipment. Generally they wear a small film of the dental type so that when the film is developed each operator knows to how much radiation he or she has been exposed.

Physical quantity	Unit	SI unit	Conversion
exposure	rontgen (R)	coulomb kilogram (C/kg)	1 C/kg = 3876 R 1 R = 2.58 × 10^{-4} C/kg
activity	curie (Ci)	becquerel (Bq) 1 Bq = 1 s^{-1}	1 Bq = 2.7 × 10^{-11} Ci 1 Ci = 3.7 × 10^{10} Bq
absorbed dose	rad (rad)	gray (Gy) 1 Gy = 1 J/kg	1 Gy = 100 rad 1 rad = 0.01 Gy
equivalent dose	rem (rem)	sievert (Sv) 1 Sv = 1 J/kg	1 Sv = 100 rem 1 rem = 0.01 Sv

Fig. 6.5 Radiation survey meter



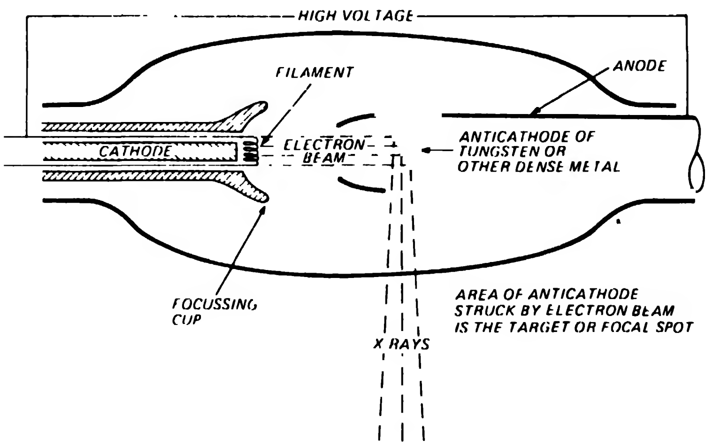
The most stringent precautions are taken to protect workers from the harmful effects of radiation and the operation, storage and transport are covered by British Standards, HMSO and Department of the Environment and ISO publications, etc. Students requiring further information should consult the literature on industrial radiography published by the film manufacturers and the suppliers of radioisotopes.

X-ray method

X-rays are produced by an X-ray tube which consists of an evacuated glass bulb with two arms. One arm houses the cathode, a filament which is heated by an electric current as in an electric light bulb, and this heated filament gives off a stream of electrons (negatively charged particles). In the other arm is the anode, which is a metal stem (see Fig. 6.6). By placing a high voltage of the order of 30 500 kV and upwards between anode and cathode the electrons are attracted at high speed to the anode and are focussed into a beam by means of a focussing cup. Fixed in the anode at an angle to the electron beam is the anticathode. This is a dense, high melting point slab of metal such as tungsten, on to which the electron beam impinges and is arrested. The resulting loss of kinetic energy appears as heat and X-rays and the latter emerge from the tube at right angles to its axis (Fig. 6.6). The tube current, which indicates the intensity of flow of the electrons, is in mA and the intensity of the radiation is somewhat proportional to this mA value.

The hardness of X-rays is their penetrating power, which increases with their energy and is inversely proportional to their wavelength. Those with short wavelength are hard rays and those with long wavelength, soft rays.

Fig 6.6 Diagram of X-ray tube



Usually soft radiation has about 20–60 kV, hard rays 150–400 kV, while very hard rays may have over 400 kV on the tube.

Since only part of the kinetic energy (0.1% at 30 kV and 1% at 200 kV and increasing) is converted into radiation, the remaining energy is transformed into heat so that the cathode must be cooled by: (1) radiation, (2) convection or (3) forced circulation by fluid, depending upon the type of tube. The area of the anticathode must be sufficiently large to avoid overheating or burning.

The rays can penetrate solid substances but, in doing so, a certain proportion of the rays is absorbed and the amount of the absorption depends upon the thickness of the substance and its density. The denser and thicker the substance, the smaller the proportion of X-rays that will get through. X-ray films are made of many layers on a base of cellulose triacetate or polyester, the small silver halide crystals which are sensitive to the rays being suspended in gelatine.

The film is placed in a rigid or flexible cassette with intensifying screens on either side so as to improve the image. The weld or object to be radiographed is placed on the cassette in the path of the rays as shown in Fig. 6.7 and after exposure for a short time, depending upon the thickness of the object, the film is developed either manually or automatically. The weld will appear as a light band across the X-ray negative, Fig. 6.8. Any defects in the weld can be seen as dark areas of faults such as blowholes, porosity, etc. Tungsten inclusions as in TIG welding will appear as very light patches, as the tungsten in very dense (Fig. 6.8*c*). It can be seen that the X-ray film is really a shadowgraph.

Small pipe welds can be X-rayed by directing the rays at an angle to the pipe axis as shown in Fig. 6.9.

Fig. 6.7

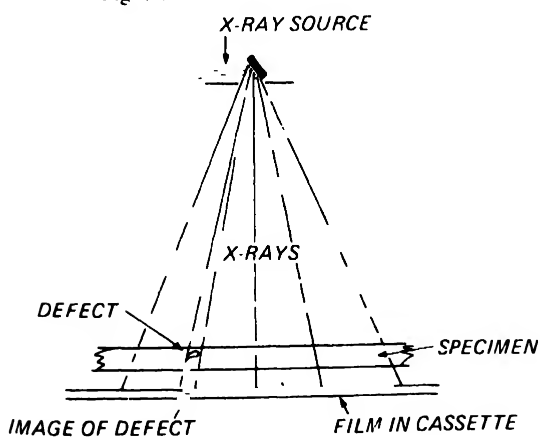
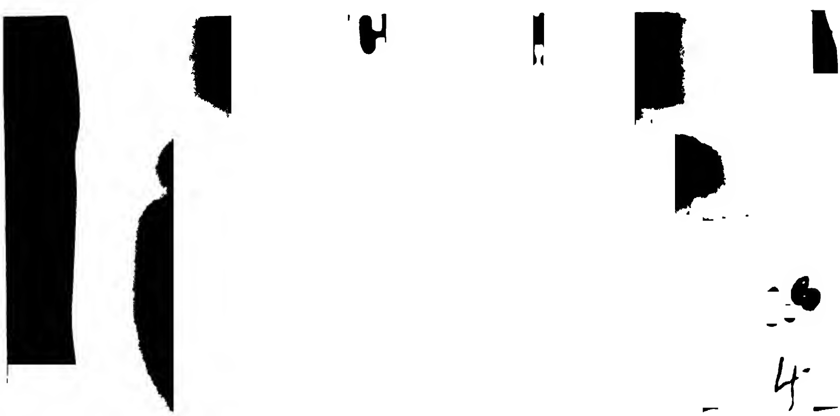


Fig. 6.8 (*a*). Double operator TIG process Material. Aluminium magnesium alloy plate ASTM SB209-5183 (N8) 8 mm thickness Square butt with 4 mm gap preparation. Current 115 A. TIG process alternating current manual double operator vertical with zirconiated electrodes, welding both sides of the joint simultaneously Wire diameter 3 mm, type BS 2901 Pt 4 5556A (NG61) Shielding gas argon The radiograph shows porosity and oxide inclusions probably associated with stop start region ASTM – American Society Testing and Materials, AWS – American Welding Society, ASME – American Society of Mechanical Engineers

Fig 6.8 (*b*) Material Stainless steel pipe, 3 mm thickness BS 970 Pt 4 304S12, AISI 304L. Chromium 18%, nickel 10%, carbon 0.03% Current 120 A, voltage 25 V, manual TIG Wire diameter 2 mm BS 2901 308S92 AWS 308L Chromium 19%, nickel 9%, carbon 0.03% Shielding gas argon Thoriated electrode This pipe would normally be purged In this case the purge is ineffective resulting in uneven penetration profile The line showing is secondary penetration without back purge which has occurred during the filling pass



To obtain a correctly exposed negative and thus ensure that the smallest defect is visible, image quality indicators (IQI) are used. These may be of the wire type (DIN) with several parallel wires of varying diameter, the sensitivity being the number of the thinnest wire that is just visible on the radiograph. An American method uses small metal plates of aluminium,

Fig. 6 8 (*c*) Material Aluminium magnesium alloy ASTM SB210 5154-0 (N5) 6 mm thickness Single preparation with permanent backing strip Current 180 A, alternating current manual TIG Wire diameter 3 mm type BS 2901 5556A (NG61) Shielding gas argon Zirconiated electrode Showing large tungsten inclusion

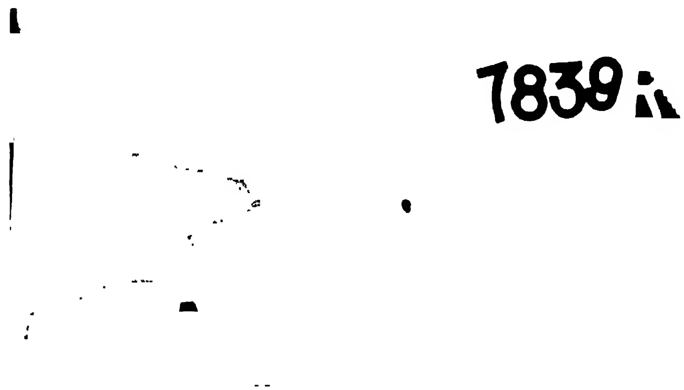
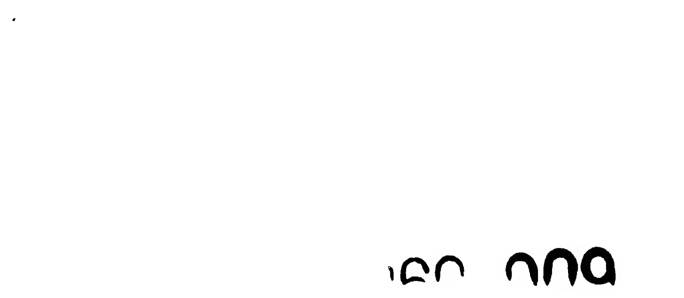


Fig 6 8 (*d*) Submerged arc weld circumferential seam Cylinder diameter 2 m Material Carbon steel BS 4360 080M50 (43A) thickness 7 mm Square butt preparation with permanent backing strip Current 440 A, voltage 32 35 V, electrode + ve, speed of travel 500 mm min Wire BS 2901 grade 18, diameter 3 2 mm Acid fused flux Weld produced from one side only The scalloped effect on the radiograph is due to a gap between backing strip and shell resulting in roll under There is also a large cavity apparent This radiograph was made with an iridium-192 (gamma-ray) capsule since reduced access prevented use of the X-ray tube on this weld area



copper, steel, etc., their thickness being usually 2% of the material being radiographed. Small holes, of diameter which are multiples of the plate thickness, are drilled in the plates and the quality of the image is given by the smallest diameter hole visible on the radiograph. British (BWRA) indicators use step wedges of increasing thickness and the holes drilled in each step are the thickness of the step, the last number visible indicating the sensitivity. These can also be used, neglecting the perforations, as ordinary stepped wedges and noting the thinnest visible step (Fig. 6.10).

The flow of electrons within the tube is measured in mA (the cathode current) and the high voltage required between anode and cathode is generally obtained by using the self-rectifying action of the tube with its heated filament. Electron flow is from cathode to anode as long as the anode is kept cool. As its temperature rises during the working of the tube the anode begins to emit electrons, the tube gradually ceases to be self-rectifying and the cathode filament may suffer. For this reason tube heads

Fig. 6.8 (*e*) Submerged arc weld, longitudinal seam in $2\frac{1}{2}$ m diameter pipe. Plate material Carbon steel BS 4360 080M50 (43A) thickness 7 mm. Square butt preparation. Current 400–430 A, voltage 28–30 V, electrode +ve, speed of travel 500 mm/min. Wire BS 2901 grade 18, diameter 3.2 mm. Acid fused flux. Weld produced from both sides with no back chip

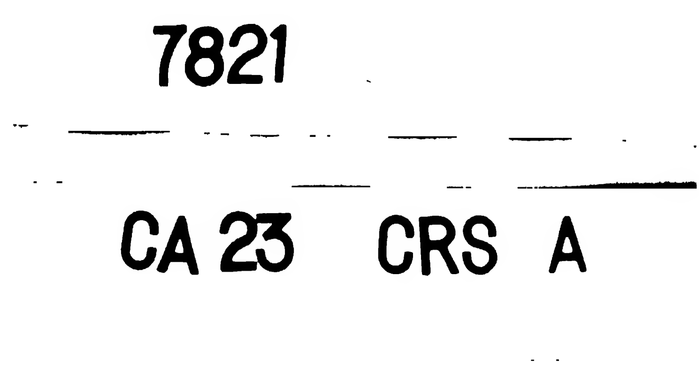
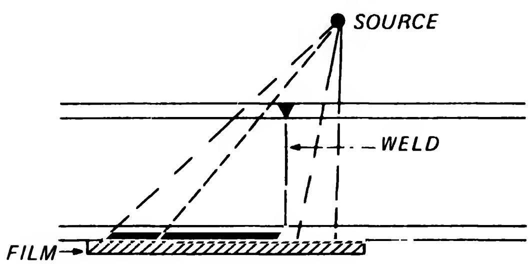


Fig. 6.9. Radiographing a pipe weld



can be fitted with a thermal trip which limits the temperature to about 75 °C and there are connexions for compressed air and water coolants. This type of rectification is half-wave and pulsating, and other means of rectification use semi-conductors with various circuits to avoid the pulsating voltage and to enable the tube to be used for longer periods without overheating.

A typical modern industrial tube unit may be directional or panoramic. The former has a self-rectifying tube, thermal trip, small focal spot, and the tube and transformer within the unit are oil insulated with a cooling system for connexion to compressed air or water. Cathode current is 4.0–8.0 mA and depends upon the tube size. They are available for thicknesses of steel from 25 mm to 75 mm with a kV range of 55 to 300.

The panoramic tube has a similar specification but the tube has a conical target and the 360° forward throw unit enables one-shot exposure of pipe welds to be made as the unit will pass into a 230 mm diameter opening. A lead belt with a radiation port is also supplied to screen the radiation during warm up and can be used to convert the tube to directional function by removal of the lead cover. For pipe exposures the film is fastened to the exterior of the pipe with the tube inside the pipe (Fig. 6.11).

The automatic control unit for the tube head works off 110 or 240 V a.c. circuits and includes an automatic build-up of high tension and tube current. This will operate after initial exposure by manual regulation of the mA and kV controls and repeat exposures can be made by pressing the 'in'

Fig. 6.10. Image quality indicator (penetrameter)

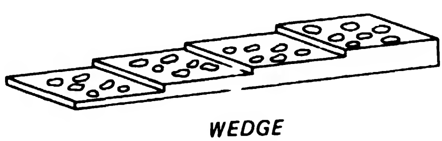
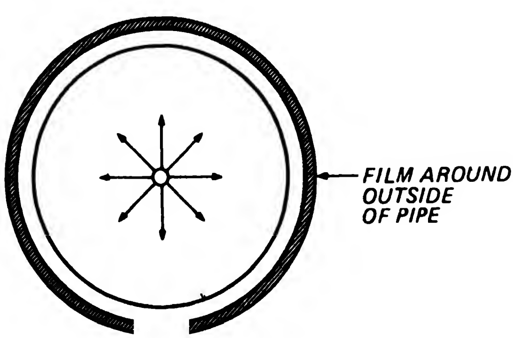


Fig. 6.11. One-shot examination of pipe weld with gamma-ray source or panoramic X-ray tube.



button. The head has also a rotatable D ring which is used for positioning during exposure and for carrying (Fig. 6.12).

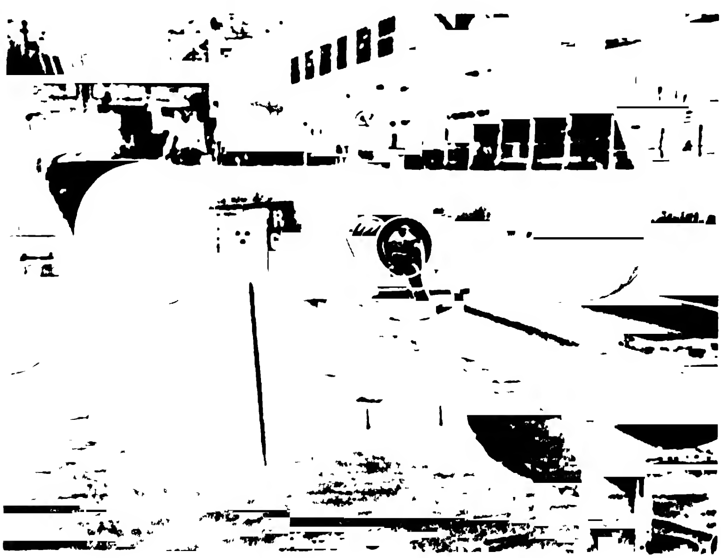
Gamma-ray method

Like X-rays, gamma-rays show a shadowgraph on a sensitized film and are interpreted in the same way.

The advantages of radioisotope sources for radiographic purposes are that they need no power supply nor cooling system. Their small focus makes them very suitable for weld inspection in narrow pipes and because some radioisotopes have high powers of penetration, thick specimens can be radiographed at shortened exposure time. They have, however, harder radiation than an X-ray tube so that the image has less contrast and interpretation is more difficult. Also the activity decreases appreciably with those radioisotopes that have a short half life so that their radioactivity depends upon the time, since renewal, and a time activity curve must be consulted when using them The radioactivity of the source cannot be varied or adjusted and since it cannot be switched off, it has to be effectively shielded.

The radioactive source is a pellet of a substance encased in a welded stainless steel container about 15 mm long by 5 mm diameter. The pellet is a cylinder of the pure metal cobalt-60 and iridium-192 and a pressed and sintered pellet of thulium dioxide thulium-170 (Fig. 6.13). These radioactive pellets do not induce radioactivity in the container and the source can be

Fig. 6.12 Positioning of X-ray tubes



returned, after a certain period depending upon its half life, to the makers to be re-energized in an atomic reactor.

The source must be stored inside a container with a dense radiation shield, usually made of lead, tungsten or even depleted uranium, where it is kept until actually in use. One type has a shutter mechanism for exposure, another type has the source mounted inside the removable portion of the shield, which can be detached and used like a torch so that the radiation appears forwards, away from the operator's body and shielded in the backwards direction. This type is useful for most work, including pipe welds.

The third type shown in Fig. 6.14*a* and *b* has the radioisotope mounted on a flexible cable and contained within a shielded container. It can be pushed along the guide tube by remote control and can be positioned in otherwise awkward places. With this type, positioning and source changing is easily performed. Pipeline crawlers for various diameter pipes are used, carrying the radioisotope and enabling it to be positioned in the pipe centre to give a radial beam of radiation when exposed, Fig. 6.11. The film is placed around the outside of the pipe enabling the radio-inspection at that point to be performed with one exposure. The crawler can be battery operated and travels on wheels with forward, reverse, expose and stop controls, the positioning within the pipes being controlled to a few millimetres accuracy.

Examples

Source	Pellet size (mm) diamond length	Maximum equivalent activity (Ci)	Approximate absorber dose in air at 1 m (mGy h)
cobalt-60	2 × 2	10 15	110 170
iridium-192	2 × 2	50	210

Fig. 6.13 Typical capsule for cobalt-60 and iridium-192 Material, stainless steel

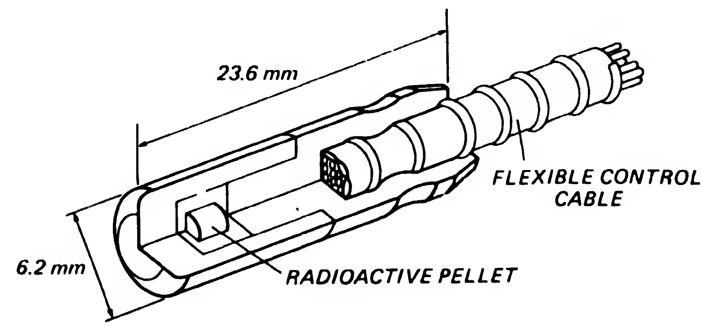


Fig. 6.14 (*a*). Remote control exposure container (shutterless)

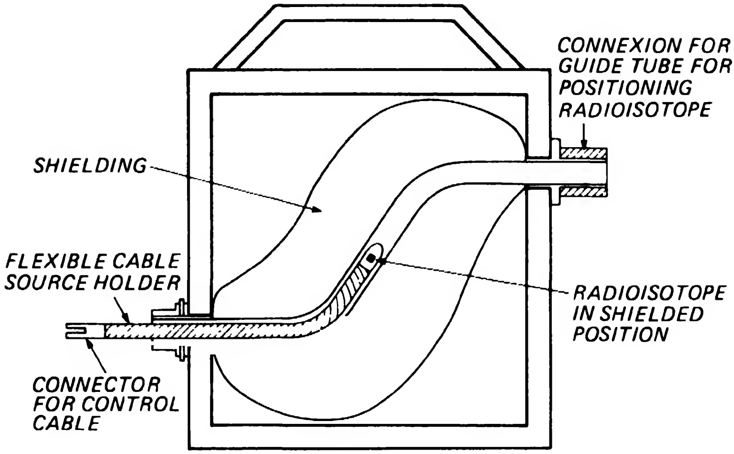
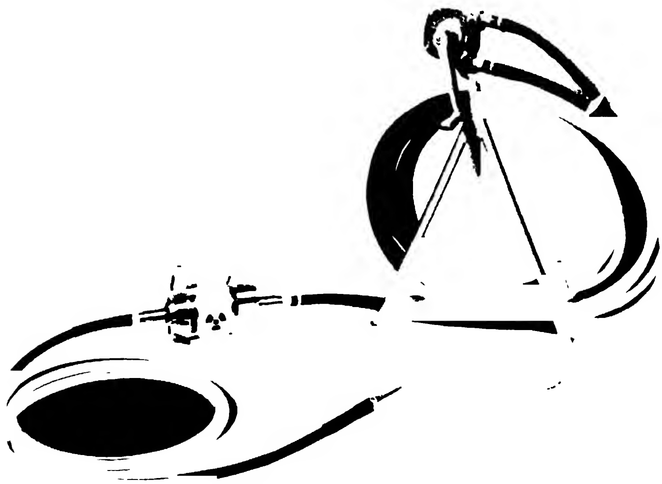


Fig. 6.14 (*b*)



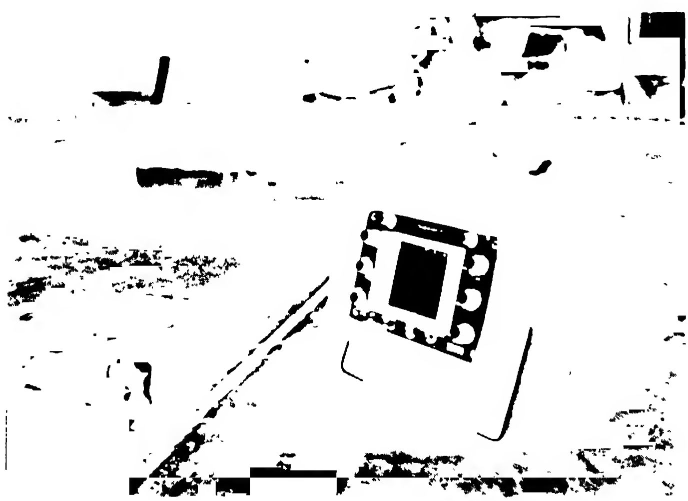
Ultrasonic testing

Ultrasonic testing employs waves above the frequency limit of human audibility and usually in the frequency range 0.6 to 5 MHz. A pulse consisting of a number of these waves is projected into the specimen under test. If a flaw exists in the specimen an echo is reflected from it and from the type of echo the kind of flaw that exists can be deduced.

The equipment comprises an electrical unit which generates the electrical oscillations, a cathode ray tube on which pulse and echo can be seen, and probes which introduce the waves into the specimen and receive the echo. The electrical oscillations are converted into ultrasonic waves in a transducer which consists of a piezo-electric element mounted in a perspex block to form the probe, which, in use, has its one face pressed against the surface of the material under test. When a pulse is injected into the specimen a signal is made on the cathode-ray tube, Fig. 6.15. The echo from a flaw is received by another probe, converted to an electrical e.m.f. (which may vary from microvolts to several volts) by the transducer and is applied to the cathode ray tube on which it can be seen as a signal displaced along the time axis of the tube from the original pulse (Fig. 6.16*a*).

The first applications of ultrasonics to flaw detection employed longitudinal waves projected into the specimen at right angles to the surface (Fig. 6.16*b*). This presented problems because it meant that the weld surface had to be dressed smooth before examination, and more often than not the way in which the flaw oriented, as for example lack of penetration, made detection difficult with this type of flaw. The type of wave used to overcome these disadvantages is one which is introduced into the specimen at some distance from the welded joint and at an angle to the surface (e.g. 20°) and

Fig 6 15



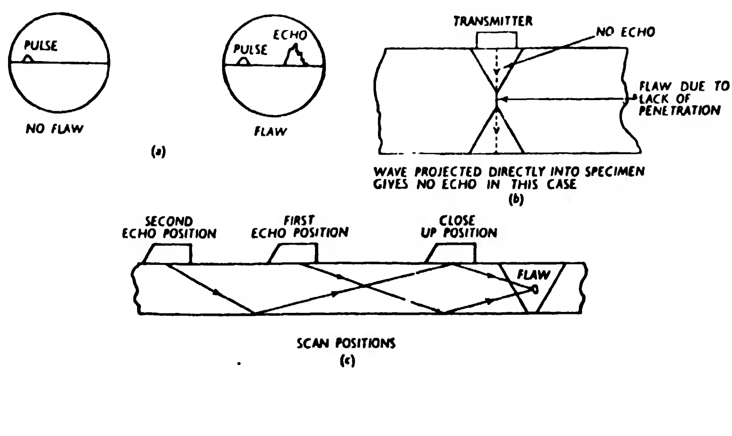
is known as a shear wave. The frequency of the waves (usually 2.5 and 1.5 MHz for butt welds), the angle of incidence of the beam, the type of surface and the grain size, all affect the intensity of the echo which is adjustable by means of a sensitivity control. The reference standard on which the sensitivity of the instrument can be checked consists of a steel block 300 × 150 × 12.7 mm thickness with a 1.6 mm hole drilled centrally and perpendicularly to the largest face, 50.8 mm from one end. Echoes are obtained from the hole after 1, 2 or 3 traverses of the plate (Fig. 6.16*c*) and from the amplitude of the echo the intensity from a hole of known size can be checked.

Three types of probe are available:

(1) A single probe which acts as both transmitter and receiver, the same piezo-electric elements transmitting the pulse and receiving the echo. The design of the probe is complicated in order to prevent reflections within the perspex block confusing the echo.
(2) The twin transmitter-receiver probe in which transmitter and receiver are mounted together either side by side or one in front of the other but are quite separate electrically and ultrasonically so that there is no trouble with interference with the echo. This type is the most popular (Fig. 6.17*a*).
(3) The separate transmitter and receiver each used independently (two-handed operation) (Fig. 6.17*b*).

To make a 'length scan' of the weld the transmitter-receiver unit is moved continuously along a line parallel to the welded seam so that all points of the whole area of the welded joint are covered by the scanning beam, and care must be exercised that by the use of too high a spread of the beam, double echoes are not obtained from a single flaw. It is evident that varying the distance from the weld to the probe varies the depth at which the main axis of the beam crosses the welded joint and moving the probe at

Fig. 6.16



right angles to the line is thus known as depth scan. A spherical flaw will have no directional characteristics and a wave falling upon its centre will be reflected along the incident path, the amplitude of the echo depending upon the size of the flaw. Cylindrical flaws behave in the same way but in the case of a narrow planar flaw it is evident that optimum echo will be received when the crack is at right angles to the wave and there will be no echo when the crack lies along the wave, but if the probe is moved to the first echo position the crack is no longer lying along the beam.

The probes must make good contact with the specimen and on slightly curved surfaces a thin film of oil is used to improve the contact. On surfaces with greater curvature, as for example when investigating circumferential welds on drums, curved probes are used.

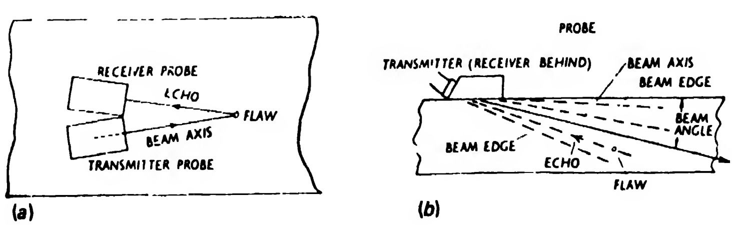
We have only considered the essential points of ultrasonic testing and it must be emphasized that there is a considerable amount of theory involved in the relationships between the distance of the transmitter from the weld and the beam angle, etc., and that a great amount of practice is required to interpret correctly the echoes received and from them decide the nature and position of the flaw. See also BS 3923, *Methods for ultrasonic examination of welds*, Parts 1 and 2.

Application of load

An illustration of this method is furnished by the hydraulic test on boilers. Water is pumped into the welded boiler under test (the safety valve if fitted having been clamped shut) to a pressure usually $1\frac{1}{2}$ to 2 times the working pressure. Should a fault develop in a joint, the hydraulic pressure rapidly falls without danger to persons near, such as there would have been if compressed air or steam had been used.

In the same way, partial compressive or tensile loads may be applied to any welded structure to observe its behaviour. The method adopted will, of course, depend on the nature of the work under test.

Fig 6 17



Destructive tests

These may be divided as follows:

(1) Tests capable of being performed in the workshop.

(2) Laboratory tests, which may be divided as follows: (1) microscopic and macroscopic, (2) chemical, analytical and corrosive, (3) mechanical.

Workshop tests

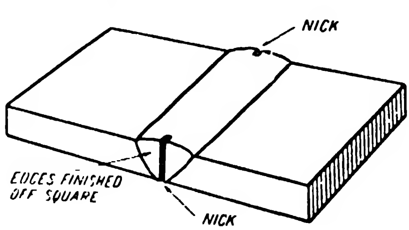
(The student is advised to study BS 1295, *Tests for use in the training of welders*, which gives standard workshop tests for butt and fillet welds in plates, bars and pipes.)

These are usually used to break open the weld in the vice for visual inspection. When operators are first learning to weld, this method is very useful, because as a rule the weld contains many defects and, when broken open, these can quickly be pointed out. Little time is thus lost in finding out the faults and rectifying them. As the welding technique of the beginner improves, however, this test becomes of much less value. Obviously much will depend on the actual position of the specimen in the vice, whether held on the joint or just below it. Also on the hammering, whether heavy erratic blows are used or a medium-weight, even hammering is given. In addition, if the weld metal is stronger than the parent metal, fracture may occur in the parent metal and thus the weld itself has hardly been tested. We can make sure that the specimen will break in the weld and afford us opportunity for examination by making a nick with a hacksaw as shown on each end of the weld, having previously filed or ground the ends square (see Fig. 6.18).

Another useful method for determining the ductility of the weld is to bend the welded specimen in the vice through 180° with an even bending force. Any cracks appearing on the weld face will indicate lack of ductility. A better method of conducting this test will be described later (see Fig. 6.19).

A useful workshop test, for use in the case in which the welded parts have

Fig 6.18. Specimen for 'nick bend' or 'nick break' test



to be heated up or even forged after welding, consists of actually forging a test specimen after welding. It is always advisable to apply the tests given later also, such as tensile, in order to obtain the ultimate strength of the weld.

Workshop tests are very limited, and their chief advantage is the little time taken to perform them. They are useful during training of welders, but little knowledge of the weld can be gained from them. The visual method, as previously explained, is a valuable addition to the workshop methods given above.

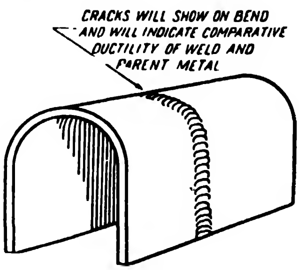
Microscopic and macroscopic tests

Microscopic tests. The use of the microscope is very important in determining the actual structure of the weld and parent metal. When a polished section of the weld is observed with the eye, it will look completely homogeneous if no blowholes or entrapped slag are present. On the other hand, if a section is broken open, as in the nick bend test, it may be found that there is a definite crystal-like structure. Since, however, this type of section may have broken at the weakest line, we must take a section across any desired part of the weld in order to have a typical example to examine. Specimens to be microscopically examined are best cut by means of a hacksaw. Any application of heat, as for example with gas cutting, may destroy part of the structure which it is desired to examine. If this specimen was polished by means of abrasives in the usual commercial way, when observed under the microscope it would be found to be covered with a multitude of scratches.

The best method of preparation is to grind carefully the face of the specimen after cutting on a water-cooled slow-running fine grinding wheel of large diameter, care being taken to obtain a flat face. Polishing can then be continued by hand, using finer abrasives, finally polishing by the polishing wheel, using rouge or aluminium oxide as the abrasive.

In order to bring out the structure of the section of metal clearly, the surface must now be 'etched'. This consists of coating it with a chemical

Fig. 6.19



which will eat away and dissolve the metal. Since the section is a definite structure consisting of composite parts, some are more easily dissolved than others, and thus the etching liquid will bring up the pattern of the structure very clearly when observed under the microscope.

The etching liquids employed (BS 1295) depend on the metal of the specimen. For steel (including iron) a 1–2% solution of nitric acid in alcohol is used. For stainless steel, austenitic and chromium 12–14%, use 5 g ferric chloride, 50 ml HCl (conc.) and 100 ml water. For aluminium and its alloys use a 10–20% caustic soda (NaOH) solution and for magnesium alloys 2% nitric (conc.) solution in alcohol. For brass, copper and bronze the solution can be 50% nitric acid and 50% water. In the above, the solutions using alcohol should be made up as required due to the evaporation of the alcohol.

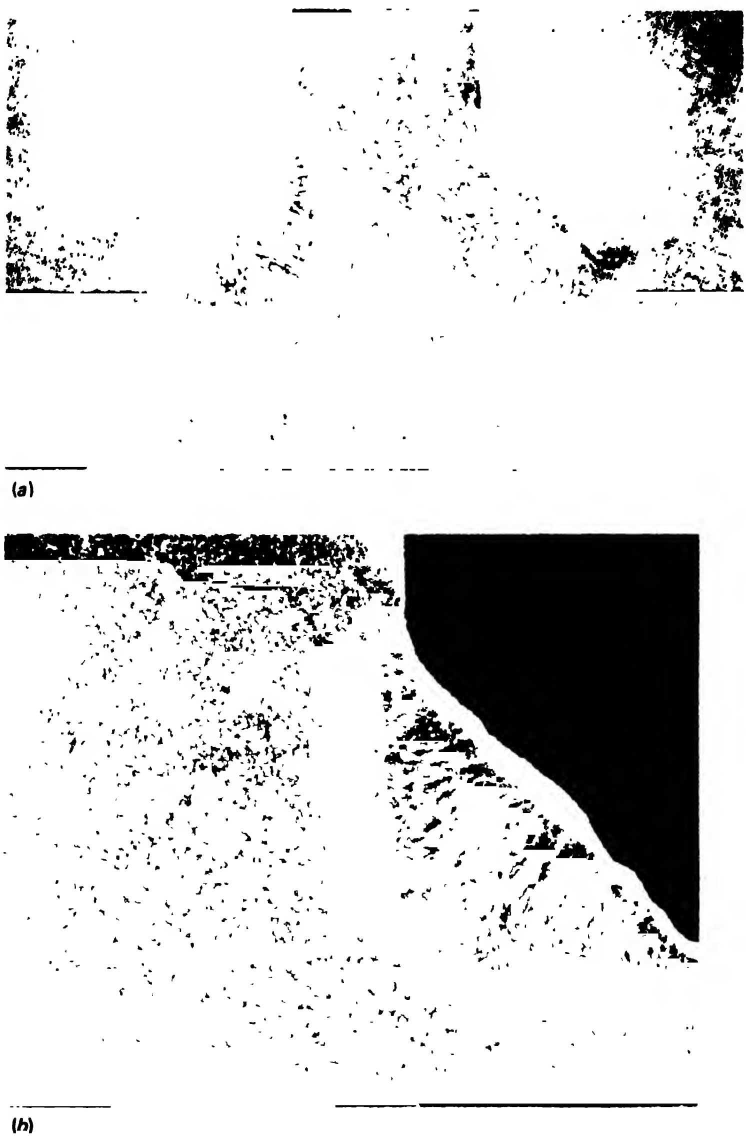
Most of the microphotographs in this book were prepared by etching with the 2% nitric acid solution in alcohol.

The length of time for which the etching liquid remains on the metal depends on the detail and the magnification required. After etching is complete, the liquid is washed off the surface of the specimen to prevent further action. For example, if steel etched with picric acid is to be examined at 100 diameters, etching could be carried out from 25 to 35 seconds, giving a clear, well-cut image. If this, however, was observed under the high-power glass of 1000 diameters, it would be found that picric acid had eaten deeply into the surface, and the definition and result would be extremely poor. Thus, for high magnification, the etching would only need carrying out for 5–10 seconds. Naturally, however, the time will vary entirely with the etching liquid used, the power of magnification and the detail required.

When the section is prepared in this way and the whole crystal structure is visible, the exact metallic condition of the weld can be examined, together with that of the surrounding parent metal. For example, examination of microphotographs of steel at 150 to 200 diameters will indicate the size of the grain, the arrangement of pearlite and ferrite. Increasing magnification to 1000 diameters will indicate the presence of oxides or nitrides, oxides being shown up as fine cracks between the crystals (producing weakness) (Fig. 2.19), and iron nitrides as needle-like crystals (producing brittleness) (p. 106). From this, the metallurgist can tell the suitability of the weld metal, how well the structure compares with that of the parent metal, and its probable strength. This study or test plays an important part in the manufacture of new types of welding rods. Microphotographs of varying magnification are used in various parts of this book to illustrate the structures referred to.

Macroscopic tests. This method consists, as before, of preparing a cross-section of the weld by polishing and etching. It is then examined either with a low-power microscope magnifying 3 to 20 diameters or even with a magnifying glass. This will show up any cracks, entrapped slag, pin-size blow or gas holes, and will also indicate any coarse structure present (Fig. 6.20).

Fig. 6.20
(*a*) Fillet weld, single-run each side, with good penetration and no undercut
(*b*) Fillet weld, two runs on one side (× 3) Note good fusion



The etching fluids most suitable for macroscopic examination are:

Steel and iron: 10% iodide, 20% potassium iodine and 70% distilled water; 10 to 20% nitric acid in water; 8% cuprous ammonium chloride in water.

Copper: 25% solution of nitric acid in water; ammonium hydrate; nitric acid in alcohol.

Brass and bronze: 25% solution of nitric acid.

Aluminium and aluminium alloys: 10% solution of hydrofluoric acid in water.

The macrographic examination of welds can easily be undertaken in the workshop, using a hand magnifying glass, and the degree of polish required is not so high as for microscopic examination. The microscope, however, will obviously bring out defects and crystal structures which will not be apparent in the macrograph.

Sulphur prints. This is an easy method by which the presence of sulphur, sulphides and other impurities can be detected in steel. It is not suitable for non-ferrous metals or high-alloy steels.

The principle of sulphur printing is that a dilute acid such as sulphuric will attack sulphur and sulphides, liberating a gas, hydrogen sulphide (H_2S), which will stain or darken bromide or gaslight photographic paper.

To make a sulphur print, the specimen is first prepared by filing or machining and then by rubbing by hand or machine to obtain a scratch-free surface (O grade emery). A piece of photographic paper is soaked in dilute sulphuric acid for about 3 to 4 minutes and then after excess acid has been sponged off, the paper is laid carefully on the prepared surface of the steel specimen and pressed down perfectly flat on its surface. It is left on the specimen for about 4 to 5 minutes, the edge of the paper being lifted at intervals to ascertain how it is staining. After removing it, the paper is treated as in photographic printing, namely rinsed, then immersed in a 20% hypo solution for a few minutes and then again thoroughly washed. The darker the stains on the paper the higher the sulphur content.

Chemical tests

Analytical tests are used to determine the chemical composition of the weld metal. From its composition, the physical properties of the metal can be foretold. The addition of manganese increases the toughness of steel, uranium increases its tensile strength, and these are indicated fully in the chapter on metallurgy.

Corrosive tests are used to foretell the behaviour of the weld metal under conditions that would be met with in years of service.

The action of acids and alkalis, present in the atmosphere of large industrial areas and which may have a marked effect on the life of the welded joints, can be observed, the effect in the laboratory being concentrated so as to be equal in a few days to years of normal exposure. From these tests, the most suitable type of weld metal is indicated. The following examples will serve as illustrations.

Along the sea coast, greatest corrosion takes place to those metal parts which are subject to the action both of the salt water and the atmosphere, that is, the areas between high and low tide; for example, oil-rig and landing-stage supports and caissons, and railings and structures exposed to the sea spray. By dipping welded specimens alternately in and out of a concentrated brine solution corrosion effects equal to years of exposure are produced.

Suppose it is required to compare the resistance to acid or alkaline corrosion of plates welded together with different types of electrodes. The specimens are polished and marked and then photographed. They are then rotated in a weak acid or alkaline solution. The specimens are photographed at given intervals and the degree of corrosion measured in each case. From the results it is evident which electrode will give the best resistance to this particular type of corrosion.

In the chemical industry, tanks are required for the storing of corrosive chemicals. It is essential that the welded joints should be just as proof against corrosion as the metal of the tank itself. Corrosive tests undertaken as above in the laboratory will indicate this, and will enable a correct weld metal to be produced, giving proof against the corrosion.

Evidently, then, these tests are specialized, in that they reproduce as nearly as possible, in the laboratory, conditions to which the weld is subjected.

Mechanical tests

These may be classified as follows:

(1) Tensile.
(2) Bending.
(3) Impact: Charpy and Izod.
(4) Hardness: Brinell, Rockwell, Vickers Diamond Pyramid (Hardness Vickers HV) and Scleroscope.
(5) Fatigue: Haigh and Wöhler.
(6) Cracking: Reeve.

Tensile test

As stated previously, a given specimen will resist being pulled out in the direction of its length and up to a point (the yield point) will remain

elastic, that is, if the load is removed it will recover its original dimensions. If loaded beyond the yield point or elastic limit the deformation becomes permanent.

Preparation of specimens. In order to tensile test a welded joint, specimens are cut from a welded seam and one specimen from the plate itself. This latter will give the strength of the parent metal plate. The specimens are machined or filed so as to have all the edges square, and the face can be left with the weld built up or machined flat, depending on the test required. It is usual, in addition, to cut specimens for bend testing from the same plate, and these are usually cut alternately with the tensile specimens, as shown in Figs. 6.21 and 6.24.

If the elongation is required, it is usual to machine the specimen flat on all faces and to make two punch marks 50 mm apart on each side of the weld, as shown in Fig. 6.22. Fig. 6.23*a* and *b* shows two specimens prepared for tensile test.

Preparation of all-weld metal specimens

Two steel plates approximately 200 × 100 × 20 mm thick are prepared with one face at an angle of 80° as in Fig. 6.25. The plates are set about 16 mm apart on a steel backing strip about 10 mm thick and are welded in position. The groove is built up with the weld metal under test and with a top reinforcement of about 3 mm. The welded portion is then cut out (thermally) along a line about 20 mm each side of the weld line. A

Fig 6.21

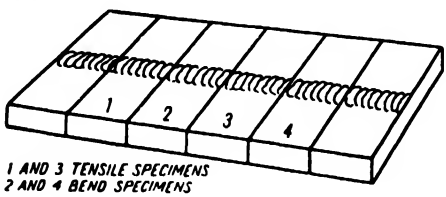


Fig. 6.22

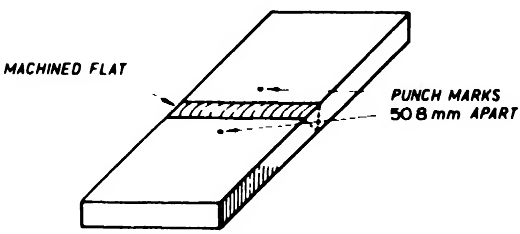


Fig. 6.23. The preparation of two specimens for tensile test with cross-sectional areas of 75 mm² and 150 mm².

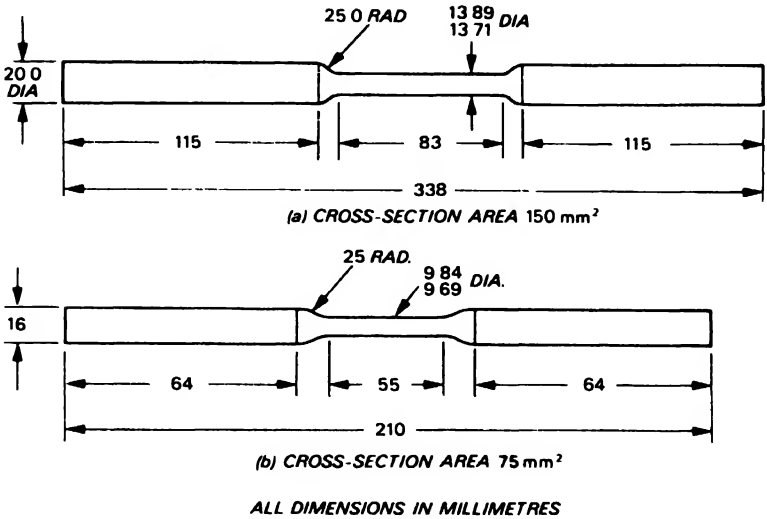
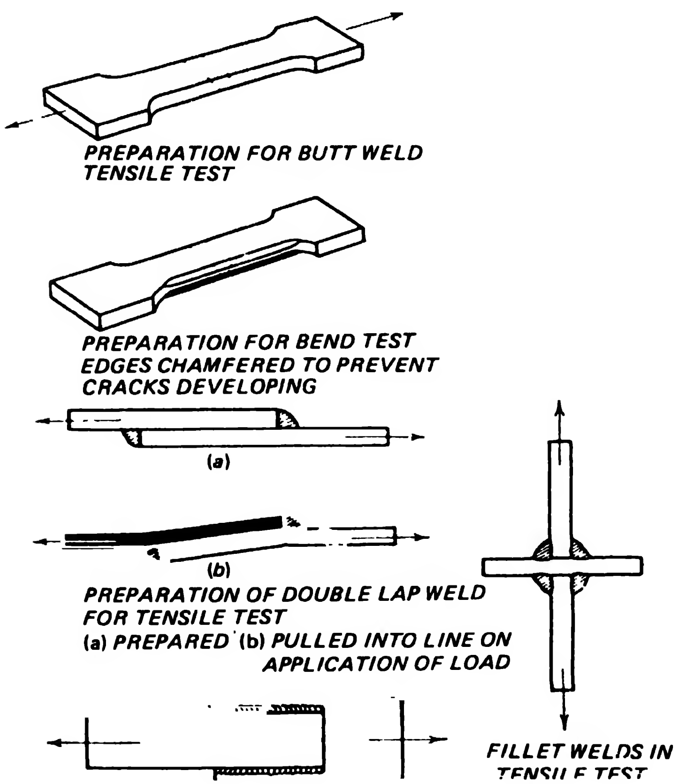


Fig. 6.24 Preparations of specimens for test.



tensile specimen is prepared from the all-weld metal as in Fig. 6.26 and a Charpy specimen as in Fig. 6.34.

The specimen is prepared from deposit well away from the parent plate as there will be effects of dilution on the two or three initial layers.

Testing machines

Present-day testing machines are available in a variety of designs suitable for specialized testing. A typical universal machine for tests in tension, cold bend, compression, double shear, transverse, cupping and punching has four ranges, 0 50, 100, 250 and 500 kN (50 tonf).

It comprises an hydraulic pumping unit (Fig. 6.27) with a multi-piston pump of variable displacement enabling the movement of the straining rams to be closely controlled. Hydraulic pressure is applied to the pistons of the rams *R* which move the cross beam *H* to which the straining wedge box is attached. The specimen under test is gripped between this and an upper wedge box connected to a series of lever balances *A* and *B*, the movement of which when load is applied is indicated on the figure. These balances or beams are mounted on hardened steel knife edges and are of deep section to

Fig. 6.25 Preparation of an all-weld metal test piece

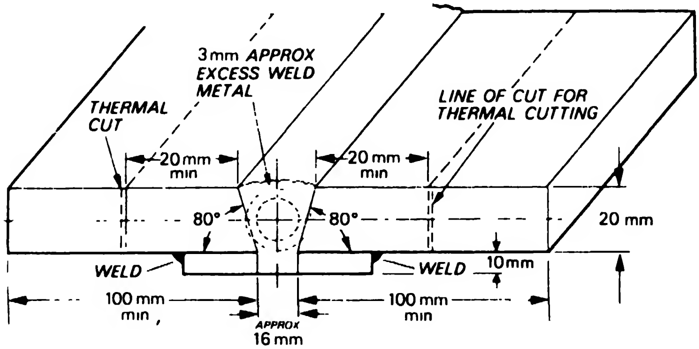
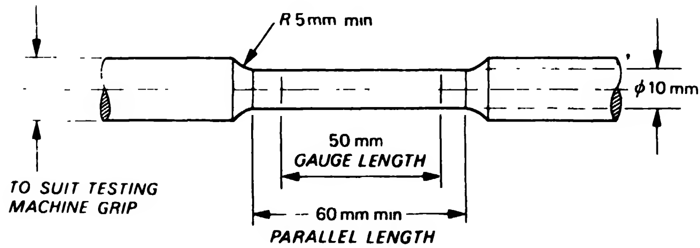


Fig. 6.26. An all-weld tensile test specimen

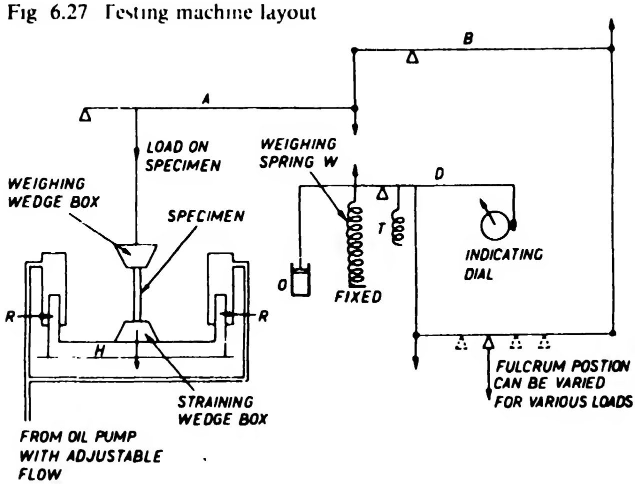


prevent deflexion. The balance arm *D* is attached at one end to the weighing spring *W* and the other end actuates the dial pointer, which moves over a scale graduated in kN. An additional spring *T* helps to keep the knife edges in contact and an oil dash pot *O* acts as a damper. The arm *C* has four fulcra, any of which can be selected by movement of a hand-operated cam depending upon the range of the test required, and at the same time the range selected is indicated on the dial.

Tensile test of a welded joint. It will be evident that a tensile test on a welded joint is not quite similar to a test on a homogeneous bar, and the following considerations will make this clear. The steel weld metal may be strong, yet brittle and hard. When tested in the machine, the specimen would most probably break outside the weld, in the parent metal, whereas in service, due to its brittleness, failure might easily occur in the weld itself. The result of this test gives the tensile strength of the bar itself and indicates that the weld is sound. It does not indicate any other condition.

If the weld metal is softer than the parent metal, when tested the weld metal itself will yield, and fracture will probably occur in the weld. Because of this, the elongation of the specimen will be small, since the parent bar will have only stretched a small amount, and this would lead to the belief that the metal had little elasticity. Quite on the contrary, however, the weld metal may have elongated by a considerable amount, yet because of its small size in comparison to the length of the specimen the actual elongation observed is small. Great care must therefore be taken to study carefully the results and to interpret them correctly, bearing in mind the properties which it is required to test.

Fig 6.27 Testing machine layout



A tensile test on an all-weld metal specimen prepared as previously explained indicates the strength and ductility of the metal in its deposited condition and is a valuable test.

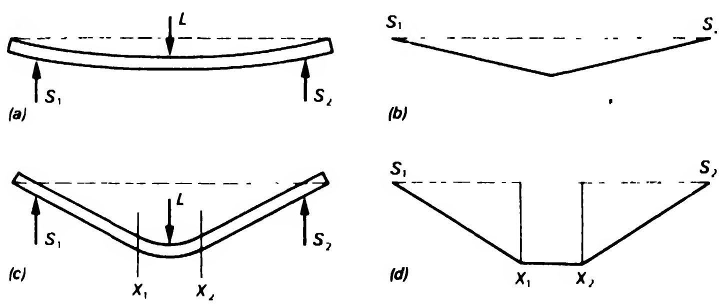
A very useful form of test is that known as the longitudinal test. In this test the weld runs along the length of the test piece. As the load is applied, if the weld metal is ductile, it will elongate with the parent metal and is placed in the machine so that the load is applied longitudinally to help to share the load. If, on the other hand, it is brittle, it will not elongate with the parent metal but will crack. Should the parent metal be of good quality and structure, the cracks will be confined to the weld metal mostly and will merely increase in width. If the parent metal is not of such good quality, the cracks will extend into the parent metal and breakage will occur with little elongation of the specimen. This test therefore indicates the quality of the parent metal as well as that of the weld metal.

Torsion test. This test is useful to test the uniformity of work turned out by welders. A weld is made between steel plates V'd in the usual manner, and a cylindrical bar is turned out of the deposited metal. This specimen is then gripped firmly at one end, while the other end is rotated in a chuck or other similar device, until breakage occurs. The degree of twist which occurs before breakage will depend upon the type of metal under test.

Bend test (for ductility of a specimen)

In this test the bar is prepared by chamfering the edges to prevent cracking (if it is of rectangular section), and is then supported on two edges and loaded at the centre (Fig. 6.28*a*).

Fig 6.28. Uniform bar supported at S_1 and S_2 and loaded at the centre (*a*) Beam deflected elastically (*b*) Bottom layer stress diagram for elastic deflexion, i.e. extension of bottom surface layers (*c*) Beam deformed or yielded plastically between X_1 and X_2 but with elastic deflexion between X_2S_2 and X_1S_1 (*d*) Bottom layer stress diagram when yield commences.



As the load is applied the bar first bends elastically, and in this state if the load is removed it would regain its original shape. On increasing the load a point will be reached when the fibres of the beam at the centre are no longer elastically deformed, i.e., they have reached their yield point, and the bar deforms plastically at the centre (Fig. 6.28*c*).

Further increase of load causes yielding to occur farther and farther from the centre, while at the same time the stress at the centre increases. Ultimately, when maximum stress is reached, fracture of the bar will occur. If this maximum stress is not reached, fracture of the bar will not occur for any angle of bend. The method determining the ductility of the bar from the above test is as follows. Lines are scribed on the machined or polished face of the specimen parallel and equidistant to each other across a width of about 150–250 mm. As the load is applied, the increase in distance between the scribed lines is measured, and this increase is plotted vertically against the actual position of the lines horizontally. When the bar deforms elastically the result is a triangle (Fig. 6.28*b*), termed the stress diagram, since it represents graphically the stress at these points. The stress diagram is shown for plastic deformation of the bar in Fig. 6.28*d*.

Now consider the test applied to a welded joint and let the weld be placed in position under the applied load. There are now two different metals to be considered, since the weld metal might have quite different properties from those of the parent metal (Fig. 6.29).

If the load is applied and the yield point of the weld metal is greater than that of the parent bar, plastic yield or bend will occur in the bar, and as the load is increased the bar bends plastically, as in Fig. 6.29*b*. During this bending, if the yield point of the weld metal is reached, the weld metal will flow or yield somewhat, but in any case most of the bend is taken by the bar. If the yield point of the weld metal is not reached, then all the bend will be taken by the bar.

If, however, the yield point of the weld metal is lower than that of the bar, the weld metal will first bend plastically and will continue to do so, plastic deformation occurring long before the yield point of the bar is reached (Fig. 6.29*d*). On such a small area as the weld metal has, therefore, fracture will occur in the weld metal at a small angle of bend. The stress diagrams given in Fig. 6.29*c* and *e* indicate where the greatest elongations of the fibres occur in each case.

Since the weld metal is almost always harder or softer than the parent metal the bending will not occur, therefore, equally in the weld and in the parent metal, and as a result the chief value of this test is to determine whether any flaws exist in the weld. Otherwise its value as a test of ductility of a welded specimen is very limited.

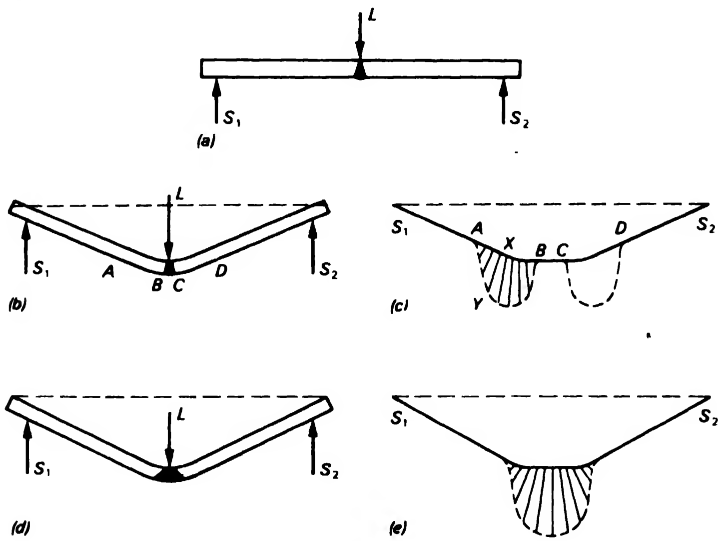
If the weld is placed so that its face is under the central applied load, fracture will occur at the root of the weld if the penetration is imperfect (Fig. 6.30).

Impact tests

We have seen when discussing notch brittleness in steel that localized plastic flow of a notch may cause cracking and that the transition from ductile to brittle state is affected by temperature, strain rate and the occurrence of notches. It should be noted that as there is no ductile–brittle transition with aluminium, impact tests are performed to a lesser degree with aluminium than with steel. Serrations, tool marks, changes of section and other discontinuities on the surface of metals that are met with in service reduce their endurance so that the term 'notch sensitivity' is applied to the degree to which these discontinuities reduce the mechanical properties. This is an important consideration in welding because, for example, any reduction in section due to undercut along the toes of butt welds and in the vertical plate in HV fillets reduces the mechanical properties of the structure.

To determine the notch brittleness (or notch toughness), impact tests are

Fig. 6.29 (*a*) Bar with inserted wedge of weld metal having mechanical properties differing from that of the bar itself, supported at S_1 and S_2 and loaded at the centre. (*b*) Load applied Yield point of weld not reached Bend taking place in the bar (*c*) Bottom layer stress diagram. Length of XY represents extension at point X (*d*) Load applied Yield point of *bar* not reached Bend taking place in the weld. (*e*) Bottom layer stress.



performed on specimens prepared with a notch of precise width, depth and shape, and the resistance which the specimen offers to breaking at the notch when hit by a striker moving at a given velocity and having a given energy is a measure of the notch brittleness.

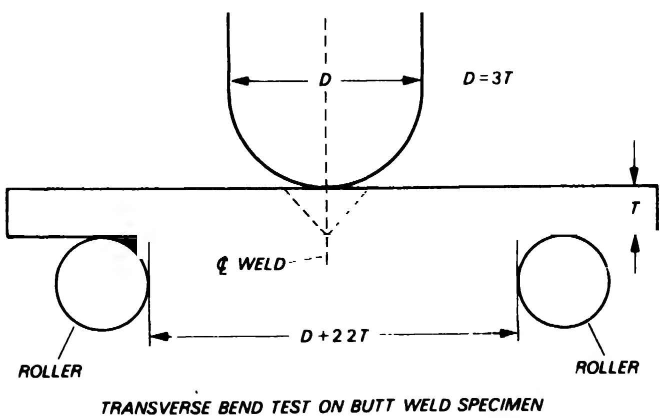
The two main tests, Charpy and Izod, employ a swinging pendulum to which a slave pointer is attached. This moves over a scale calibrated in joules as the pendulum swings and stays at the impact value of the test, being afterwards reset by hand. The pendulum tup (or bob) incorporating the striker hits the notched specimen at a given velocity and with a given energy (measured in joules). If no specimen were present the pendulum would swing unhindered to the zero position on the scale, but since energy is lost in breaking the specimen the pointer will take up a position at say x joules on the scale. This is the impact value for the specimen at the particular temperature and represents the energy lost by the pendulum in breaking the specimen.

Impact tests are being increasingly used at sub-zero temperatures in order to give indications and possibilities of brittle fracture. Diethyl ether and liquid nitrogen are used to obtain temperatures down to $-196\,^{\circ}C$ using a copper-constantan thermo-couple for temperature measurement.

Charpy and Izod machines

Machines can be Charpy and Izod combined or Charpy only or Izod only and can be manually or pneumatically operated. In manual machines the pendulum is lifted physically to the start position where it is

Fig 6.30. A typical transverse bend test Upper and lower surfaces are ground or machined flat The specimen is about 30 mm wide The bending should be through an angle of 180° over a former with a diameter three times that of the plate thickness Test should be made with (1) the weld face in tension, and (2) the root of the weld in tension



held in position by a release box which has a self-setting catch. There is a pendulum release lever and a safety lock lever which prevents accidental release of the pendulum. Pneumatically operated machines operate in a similar manner to the manual machines except that the pendulum is lifted under power to the Charpy or Izod start position and can be set for automatic release (Fig. 6.31*a* and *b*).

Machine capacities are 0–150 J (striker velocity 3–4 m/s) for the Izod machine and 0–300 J (striker velocity 5–5.5 m/s) with an optional 0–150 J for the Charpy machine. On the combined machines, tups and strikers are changed for the different tests and gauges are provided for the Charpy machine to check that the striker hits the specimen centrally between the anvils.

Charpy test

This test may be either with a V or a U section notch, the specimen and notch sizes being shown in Fig. 6.32. The V notch test is becoming increasingly used in Britain and is the test required for impact values in BS 639 – *Covered electrodes for the MMA welding of carbon and carbon–manganese steels.*

Fig. 6.31 (*a*) The Charpy machine; 150 and 300 joules

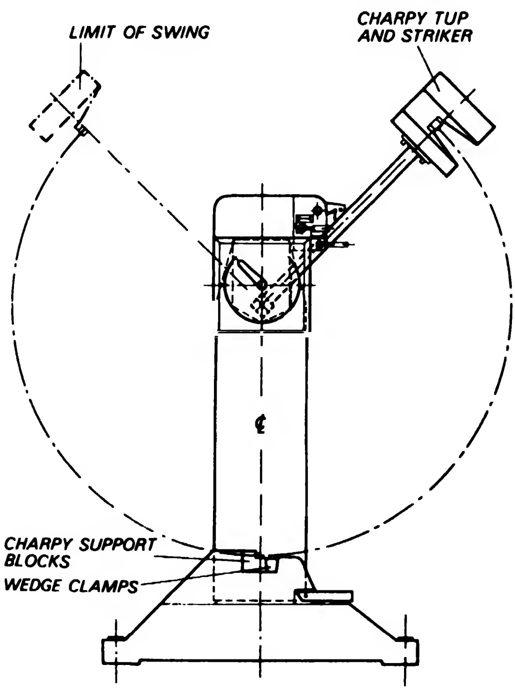
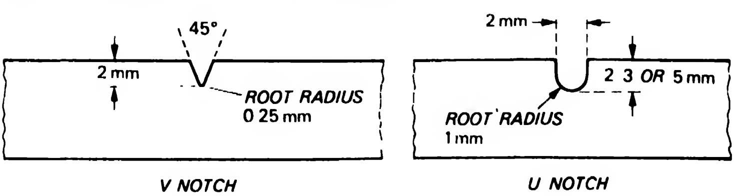


Fig. 6.31*a* and *b* indicates the method of operation of the machine. The specimen is supported squarely at its two ends by machine supports, the notch being centrally placed by means of small tongs (Fig. 6.33). The pendulum is raised to the test height and the pointer indicates 300 J on the scale. A hand lever is operated, the pendulum swings and the striker hits the specimen exactly on the side behind the notch. Energy is absorbed in fracturing the specimen and the pointer swings to say x joules on the scale, this being the Charpy value at the particular temperature on the 300 J scale for either V or U notch, whichever was chosen. Fig. 6.34*a* shows the

Fig. 6.31 (*b*)

Fig 6.32. Preparation of V and U notches



SPECIMENS 55 mm LONG AND 10 mm SQUARE SECTION

NOTCHES CENTRALLY PLACED AND AT RIGHT ANGLES TO THE LONGITUDINAL AXIS

preparation of an all-weld metal test piece and Fig. 6.34*b* shows the preparation for impact testing a weld. (See also BS 131 Pt 2, *Charpy* V *test* and Pt 3, *Charpy* U *notch test.*)

Izod test

This test is performed on a specimen with a V notch and of dimensions as in Fig. 6.35*a*. The specimen is mounted vertically in a groove in the vice wedge block assembly, which is tightened by handwheel.

Fig. 6.33. Striker and specimen for the Charpy test.

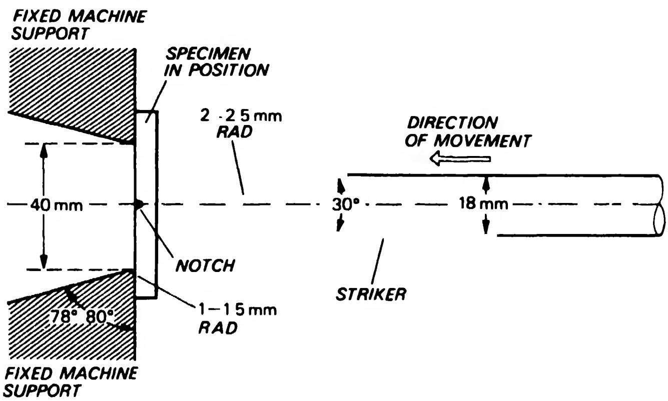
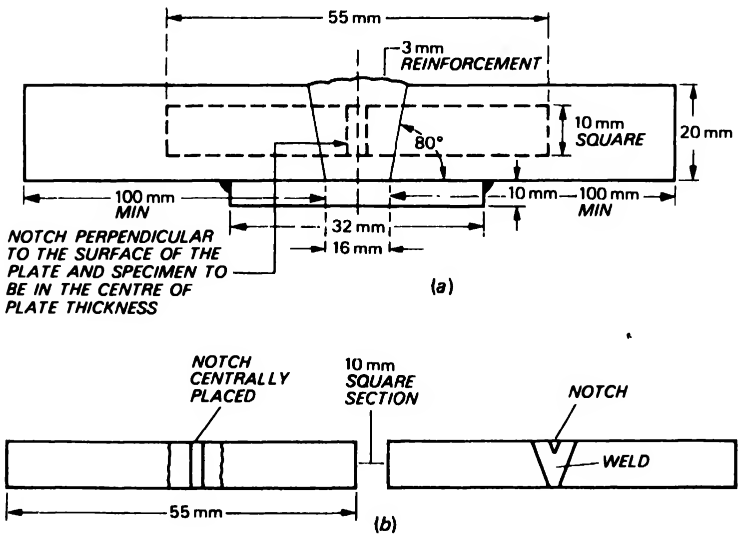


Fig. 6.34. (*a*) An all-weld metal test piece for Charpy test (*b*) The preparation for impact testing



The V notch is located facing the striker and with the base of the V exactly in line with the top edge of the vice, and is lined up with a small hand jig. The striker hits the specimen at the striking height 22 mm above the V notch (Fig. 6.35*b*).

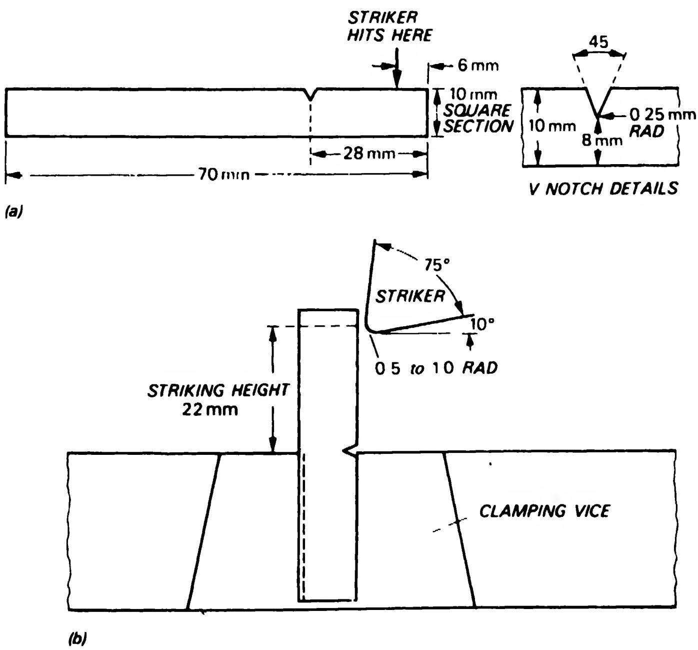
To operate the machine the pendulum is raised to the 150 J position and upon release swings as in the Charpy test and the pointer indicates the impact value in joules. Fig. 6.36 shows a combination machine with Izod release box in position and set for the Izod test and also with the Charpy release box in position. (See also BS 131 Part 1.)

Hardness tests

These are useful to indicate the resistance of the metal to wear and abrasion, and give a rough indication of the weldability of alloy steels. If parts, such as tramway crossings, dredger bucket lips, plough shares or steel gear wheels, have been reinforced or built up, it is essential to know the degree of hardness obtained in the deposit. This can be determined by portable hardness testers of the following types.

The chief methods of testing are: (*a*) Brinell, (*b*) Rockwell, (*c*) Vickers Diamond Pyramid, (*d*) Scleroscope.

Fig. 6.35 The Izod test (single notch)



The ***Brinell test*** consists in forcing a hardened steel ball, 10 mm diameter, hydraulically into the surface under test. The area in square millimetres of the indentation (calculated from the diameter measured by a microscope) made by the ball, is divided into the pressure in kilograms, and the result is the Brinell hardness number or figure. Figure 6.37 shows an indentation of 4.2 mm diameter when measured on the microscope scale.

For example: if the load was 3000 kg, and the area of indentation 10 mm^2, Brinell number equals 3000 divided by 10, which is 300.

The Brinell figure can be calculated from the following:

$$\text{Brinell figure} = \frac{P}{\frac{1}{2}\pi D(D - \sqrt{(D^2 - d^2)})}$$

where P = load in kg, D = diameter of ball in mm, d = diameter of indentation in mm.

The tensile strength of mild steel in N/mm^2 is approximately 3.4 times the Brinell hardness value.

Fig 6.36 Machine for the Izod test, 0–150 joules

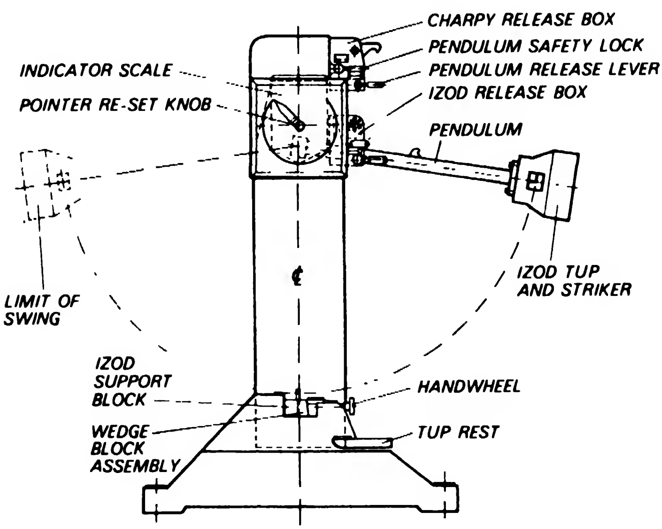


Fig 6.37. Indention made by Brinell ball in hard surface and measured by microscope scale.

Evidently the ball must be harder than the metal under test or the ball itself will deform and as a result it is used only up to a figure of about 500. See also BS 240.

Rockwell hardness test

There are three standard indenters: a diamond cone with an included angle of 120 and with the tip rounded to a radius of 0.2 mm; a 1.6 mm diameter hardened steel ball; and a 3.2 mm diameter hardened steel ball. The diamond cone or steel ball is first pressed into a clean surface under test with a load of F_1 kgf to a point *B*, distant *AB* above a reference line at *A* (Fig. 6.38*a*). A further load F_2 is now applied making a total load of $F_1 + F_2$ kgf and the indenter is pushed further into the surface to a point *C*, distant *AC* above *A*. The major load is then released leaving only the initial load F_1, and there is some recovery to the point *D*, distant *AD* above *A*. Then *BD* represents the permanent depth of indentation due to the additional load. This indentation is automatically measured on the dial of the machine and indicates the Rockwell hardness HR, the number having an added letter indicating the scale of hardness used.

In each case in the following typical scales the initial load is 10 kgf (F_1).

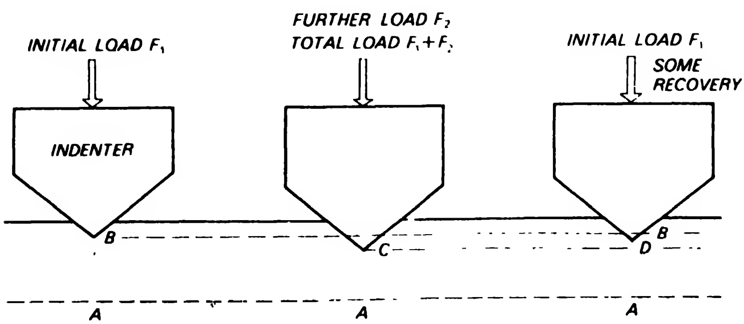
Scale A, additional load 50 kgf, total load 60 kgf, diamond indenter

Scale B, additional load 90 kgf, total load 100 kgf, 1.6 mm diameter steel ball indenter.

Scale C, additional load 140 kgf, total load 150 kgf, diamond indenter.

BD represents the permanent indentation due to the additional load. The reference plane at *A* represents the zero of the particular hardness scale, *AB* having a constant value of 100 units for the diamond indenter and 130 for the steel ball indenter. To use a testing machine the particular indenter in

Fig. 6.38. (*a*) *BD* represents the permanent indentation due to the additional load. The reference plane at *A* represents the zero of the particular hardness scale, *AB* having a constant value of 100 units for the diamond indenter and 130 for the steel ball indenter



use is fitted to the machine and the scale selected. Loads are applied automatically, the hardness number appearing on the dial (Fig. 6.38*b*) so that routine hardness tests are easily and quickly performed. See also BS 891 Pt 1 and 2.

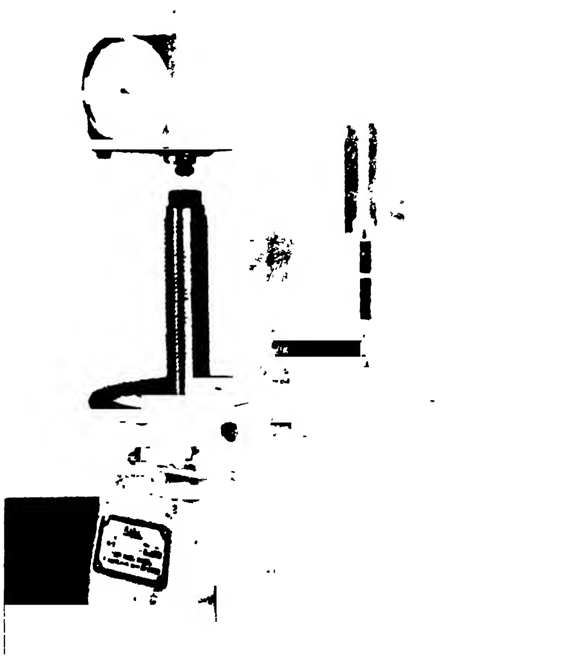
Vickers hardness test (BS 427, Parts 1 and 2)

The Vickers hardness test is similar to the Brinell test but uses a square base right pyramidal diamond with an angle of 136° between opposite faces as the penetrator. The two diagonals d_1 and d_2 mm of the identation are measured and the average calculated. The Hardness Vickers is obtained thus:

$$HV = 1.854 \frac{F}{d^2},$$

where F = load in kgf and d is the diameter of the diagonal (or the average of the diameters) (Fig. 6.39). To avoid having to perform this calculation for each reading, the diameter is obtained from an ocular reading fitted to

Fig. 6.38 (*b*) Direct reading hardness testing machine



the measuring microscope and the HV is obtained from the ocular reading with the use of a table.

The pressure, which is applied for a short time, can be varied from 1 to 120 kgf according to the hardness of the specimen under test. The Brinell number and the HV number are practically the same up to 500, the Brinell number being slightly lower (see table)

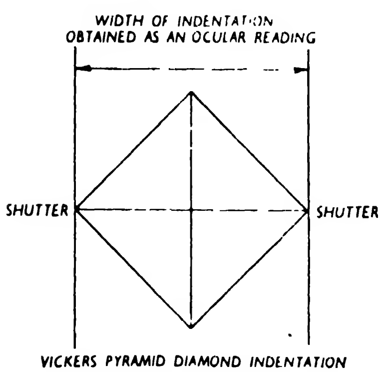
The ***Scleroscope test*** consists of allowing a hard steel cylinder, called the hammer, having a pointed end, to fall from a certain height onto the surface under test. The height to which it will rebound will depend upon the hardness of the surface, and the rebound figure is taken as the hardness figure. The fall is about 250 mm, giving with a hard steel surface a rebound height of about 150 mm, this being 90 to 100 on the Scleroscope scale.

Fatigue test

If a specimen is subjected to a continuously alternating set of push and pull forces operating for long periods, the specimen may fail due to

Brinell number	Hardness Vickers	Rockwell	
		Scale A	Scale C
59	100	43	
235	240		20
380	400		40
430	460		45
460	500		48
535	600		54
595	700		58
	800		62
	1000		68

Fig 6 39



fatigue of the molecules, and the magnitude of the force under which it may fall will be much less than its maximum tensile or compressive strength. The forces applied rise to a maximum tension, decrease to zero, rise to a maximum compression and decrease again to zero. This is termed a cycle of operations and may be written 0 maximum tension 0 maximum compression 0 and so on. Fatigue tests are based on this phenomenon exhibited by metals.

In the ***Haigh tests***, a soft-iron core or armature vibrates between the poles of an electro-magnet carrying alternating current, and is connected to the specimen under test. As alternating current is passed through the coil, the armature vibrates at the frequency of the supply (usually 50 Hz) between the poles, and the welded specimen is thus subjected to alternating push pull forces at this frequency. The alternating current, and therefore the force on the armature, rises as above: 0 maximum in one direction–0 maximum in opposite direction–0; this being, as before, one cycle of operations.

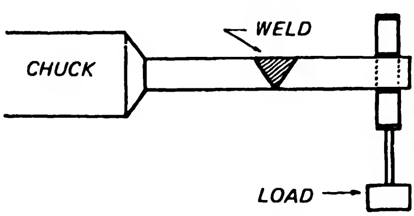
The drawback to this test is that at 3000 reversals per minute an endurance test of 10 000 000 reversals would take about 56 hours and a complete endurance test will take many days.

The latest type of electromagnetic fatigue tester gives approximately 17 000 reversals per second, and thus the required tests can be performed in a fraction of the time and the machine automatically shuts off when failure occurs.

The pick-up which causes the vibration is controlled from an oscillator and non-magnetic metals can also be tested.

In the ***Wöhler test***, the specimen is gripped at one end in a device like a chuck and the load is applied at the other end by fixing it to a bearing, as shown in Fig. 6.40. When the chuck rotates at speed, the specimen is continuously under an alternating tension and compression, tension when the face of the weld is uppermost, as shown, and compression when it is below. If the load applied is large, the specimen may be pulled out of

Fig 6.40. Illustrating principle of Wohler test



balance. These out-of-balance forces then increase the forces on the specimen, and we are unable to tell the load under which the weld failed. This can be overcome, however, by a slight modification of the machine having a bearing at each side of the joint under test and the load applied between the bearings, but the test remains the same. In conducting a fatigue test, a certain load is placed on the specimen, and this produces a certain stress. Suppose the stress produced is 140 N/mm^2; this stress varies from zero to 140 N/mm^2 tensile stress, then back to zero and to 140 N/mm^2 compressive stress and back to zero. This is a complete cycle. Low speed reversals of an applied force may be applied hydraulically over long periods to find the resistance to fatigue of a welded structure.

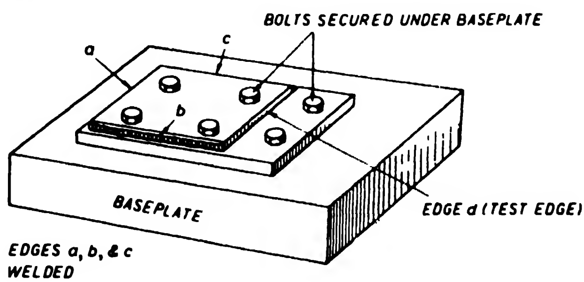
Fatigue tests are extremely useful for observing the resistance to fatigue of welded shafts, cranks and other rotating parts, which are subjected to varying alternating loads. They also provide a method of comparing the resistance to fatigue of solid drop forged and welded fabricated components.

Cracking (Reeve) test

This is used in the study of the hardening and cracking of welds and is of especial value in ascertaining the weldability of low-alloy structural steels and high tensile steels, which as before mentioned are prone to harden and develop cracks on cooling. A 150 mm square plate of the metal to be welded is placed on another larger plate of the same metal and the two are firmly secured to a heavy bed plate, 50 mm or more in thickness, by means of bolts as shown in Fig. 6.41.

Edges *a*, *b* and *c* are then welded with any selected electrode, thus firmly welding the two plates together, and they are then allowed to cool off. Edge *d* is the one on which the test run is to be deposited using the electrode under test, and evidently, since the two plates are completely restrained in movement, any tendency to crack on cooling will show in the weld on the edge *d*.

Fig. 6.41 Reeve test



After cooling, the bolts are removed and the weld examined by previously described methods for cracks. Sections can then be sawn off from the plate, the hardness of the weld tested at various points, and sections etched and examined microscopically.

It can be seen from this outline of available tests for welds that the particular test chosen will depend entirely upon the type of welded joint and the conditions under which it is to operate. These conditions will govern the tests which must be applied to indicate the way in which the weld will behave under actual service conditions.

Erichsen test (cupping)

This is used for determining the suitability of a metal for deep drawing and pressing. A punch with a rounded head is pushed into the surface of the metal, the depth and appearance of the indentation before cracking occurs being an indication of the suitability for drawing and pressing.

*Some notes on Crack Tip Opening Displacement (COD BS 5762)**

In any welded structure, from the smallest equipment to the largest unit typified by pressure vessels, oil rigs and nuclear reactors, the appearance of cracks during fabrication is a problem that is always present.

If document PD 6493 of the BSI 'Guidance notes on acceptance levels for defects in fusion welded joints' is studied, it will be realised how important the presence of defects may be since, for example, the presence of a notch may be the source of unstable crack propagation.

The Charpy impact test measures the total energy absorbed in the fracture of a specimen at various temperatures (p. 286). It enables the designer to select materials having certain impact values at selected temperatures and is used (in conjunction with other tests such as tensile, hardness, etc.) to determine the choice of parent metal, electrode or wire type and weld procedure for a given fabrication.

Crack Tip Opening Displacement (CTOD) testing is used to measure the elastic plastic toughness of the material in the ductile brittle transition. It is a method of determining the resistance to initiation of a crack which has occurred in a specimen or structure and, if specified and carried out, ensures that the structure or weldment will have sufficient tolerance to normal defects (if the results are satisfactory) and that if an

* This test (COD BS 5762) is now called crack tip opening displacement (CTOD) in amendment 4131 to avoid confusion with other displacements within the crack

ECA (engineering critical assessment) is required, all the data regarding the structure or component are immediately available.

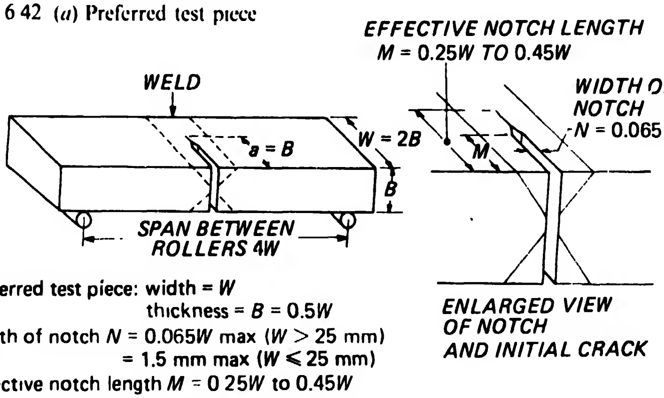
The propagation of a crack in a welded structure depends upon the material used, dimensions and acuity of a notch (if any), rate of application of the stresses, temperature, material restraint, heat input, joint restraint, pre-heat interpass temperature, weld preparation and root-run retreatment (degree of back gouge or grinding).

For the CTOD test, specimens are selected from plate or weldments, etc., the geometries of preferred and subsidiary test pieces being shown in Fig. 6.42.

Specific procedures for weldment testing have been developed by The Welding Institute and will be included in the next revisions to BS 5762.

A notch of given width and depth is milled or sawn at the required position and the specimen is then placed in a test machine and subjected to load cycling to induce a fatigue crack. The use of high speed resonance machines greatly reduces the time taken for this process. The procedure

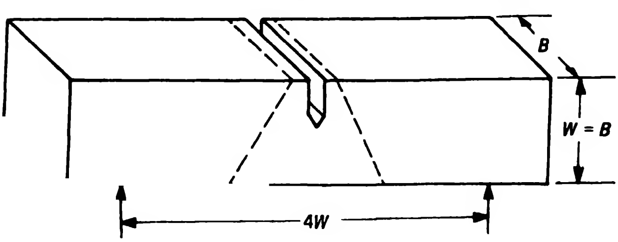
Fig. 6 42 (*a*) Preferred test piece



Preferred test piece: width = W
thickness = B = $0.5W$
Width of notch $N = 0.065W$ max ($W > 25$ mm)
= 1.5 mm max ($W \leqslant 25$ mm)
Effective notch length M = $0.25W$ to $0.45W$
Effective crack length a = $0.45W$ to $0.55W$

For plate material $a/W = 0.3$ but $a/W = 0.5$ gives greatest constraint (usually thickness notches)

Fig. 6.42. (*b*) Subsidiary test piece (usually surface notches)



for this pre-cracking together with the depth and width of the milled notch is given in BS 5762.

The test piece is then placed on a three-point bending rig on a testing machine with the load applied symmetrically about the notch (see Fig. 6.43), and a clip gauge is fixed to the mouth of the notch which has grooves machined in it or knife edges bolted to it in order to accommodate the gauge. Electrical signals from the gauge are amplified by means of a bridge circuit, and the opening of the mouth of the crack (CMOD) measures accurately the slow opening of the crack. Figs. 6.44*a*, *b* show the diameter of the rollers and the clip-gauge position while Fig. 6.44*c* shows the types of knife edge for fitting the clip gauge.

A force-sensing device fitted to the machine enables the applied load to be measured and then plotted against the clip-gauge displacement. Three typical curves are shown in Fig. 6.45.

The value of the clip-gauge measurement at the mouth of the crack is converted into the value of the CTOD using the formula on p. 301 involving, amongst other variables, the Poisson's ratio and Young's modulus of the specimen.

The CTOD is measured in millimetres and the definitions (BS 5762) involve the following variables, since δ has differing values according to the behaviour of the specimen.

Fig 6.43 Three point bending

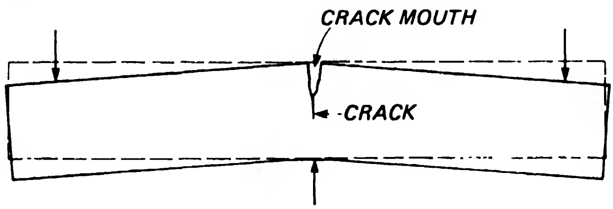


Fig 6.44 (*a*) Specimen assembled on three-point bend rig with clip gauge in position

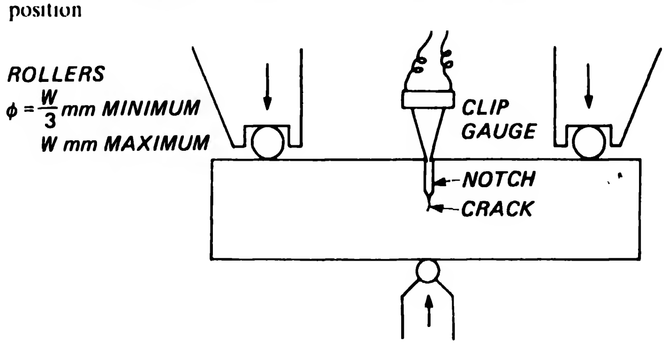
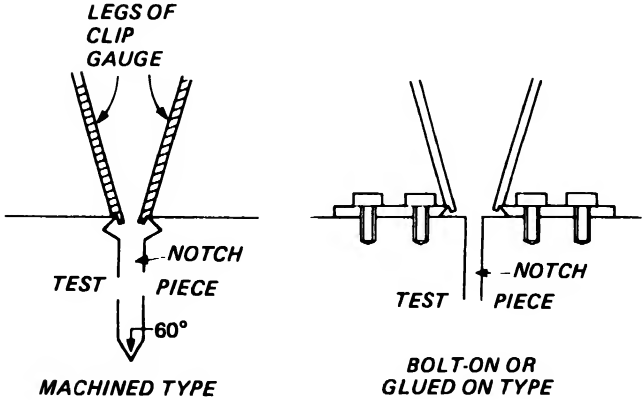


Fig. 6.44. (*b*) Specimen in position on machine

Fig. 6.44. (*c*) Knife edges for clip gauge



δ_c CTOD when brittle crack extension or pop-in begins and only applies when this is *NOT* preceded by slow stable crack growth.

δ_u CTOD when brittle crack extension or pop-in begins and only applies when this *IS* preceded by slow stable crack growth.

δ_m CTOD at the first attainment of the maximum force plateau, measured when stable ductile fracture occurs.

δ_i CTOD at the initiation of stable tearing.

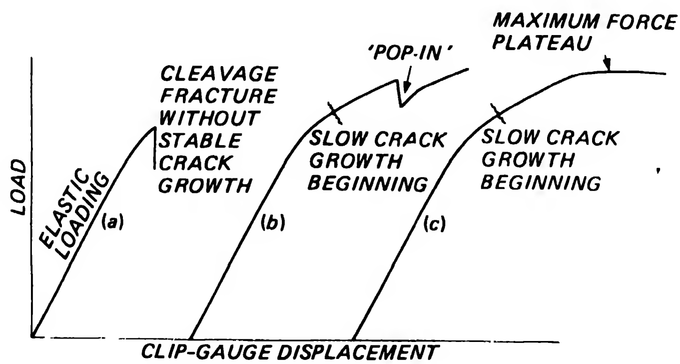
For the specific case of fully ductile behaviour, the CTOD at maximum load δ_m is measured. BS 5762 also contains guidance on additional testing to enable δ_i to be determined.

The critical CTOD values for the three curves shown in Fig. 6.45. would be defined as (*a*) δ_c, (*b*) δ_u and (*c*) δ_m.

The report of the test in each case includes the following details about the specimen:

(1) Details of the material, its condition and the location of the test piece(s) with respect to the manufactured items.
(2) Test piece thickness *B* (mm) and width *W* (mm).
(3) Loading span.
(4) Fatigue pre-cracking:
   (*a*) Fatigue stress intensity factor during propagation of the crack (in $N/mm^{3/2}$).
   (*b*) The temperature of the test piece during pre-cracking (in °C).
   (*c*) The fatigue force ratio (the ratio between the maximum and minimum load in the fatigue cycle).
(5) Test temperature (in °C).

Fig 6.45 Typical load displacement traces



(6) Rate of change of load or displacement with respect to time; if this cannot be set on the machine, the rate of change of load for the elastic portion of the loading curve together with the machine stiffness shall be recorded.

(7) Force/displacement record:
   (*a*) Plastic components of critical clip-gauge displacement (in mm).
   (*b*) Appropriate critical applied force (in N).

(8) Crack length a mm; this must be measured at three points on the crack front and the dimensions checked against the validity requirements of BS 5762.

(9) Distance of clip-gauge location from the test piece surface z mm.

(10) Critical crack opening displacement, δ_c, δ_u, δ_m mm.

(11) Any observation of fracture surface such as unintentional weld defects.

The elastic part of CTOD is estimated using the value of the equivalent stress intensity factor K at the failure load assuming plane strain conditions.

The plastic part of CTOD is determined from the plastic displacement at the crack mouth (V_p) assuming rotation of the specimen around a hinge point located at 0.4 ($W - a_0$) ahead of the crack tip.

The CTOD is then given by:

$$\delta = \frac{K^2(1-\nu^2)}{2E\sigma_Y} + \frac{0.4(W-a_0)V_p}{(0.4W+0.6a_0+z)}$$

where W = width of the specimen
σ_Y = yield strength of the material
z = knife edge thickness
a_0 = original crack length
E = Young's modulus
ν = Poisson's ratio
V_p = plastic displacement
K = plane stress intensity factor

Students requiring more information on this on-going subject must refer to BS 5762 which gives details of the many variables concerned. The various articles in *Metal Construction* (the journal of the Welding Institute) and research papers on the subject should be consulted. The fracture laboratory of the Institute is well equipped with the latest machines and undertakes CTOD testing of specimens and weldments for industry and provides exhaustive test reports on them.

7

Engineering drawing and welding symbols

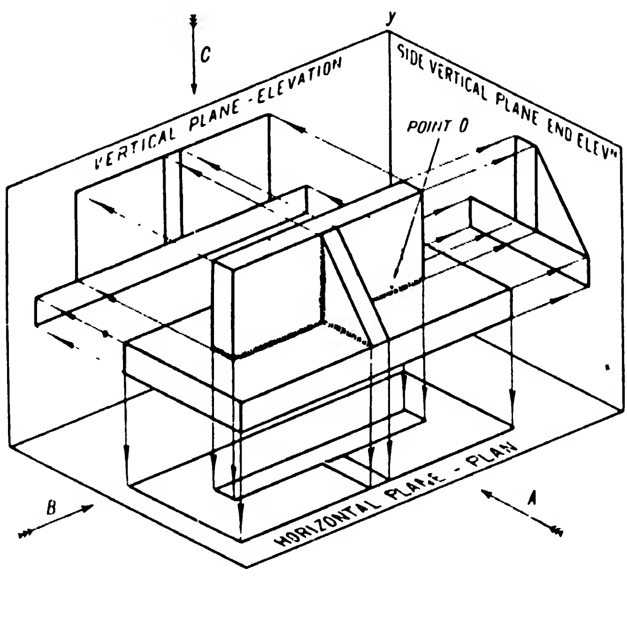
Engineering drawing

The principal method usually adopted in the making of machine drawings is known as orthographic projection.

Suppose the part under construction is shown in Fig 7.1*a*. This 'picture' is known as an isometric view. It is of small use to the engineer, since it is difficult to include on it all the details and dimensions required, especially those on the back of the picture, which is hidden.

Imagine that around the object a box is constructed (O being the corner farthest from the observer) having the sides Ox, Oy, Oz all at right angles to each other. The plane or surface of the box bounded by Ox and Oy is the

Fig 7 1 (*a*)



vertical plane, indicated by VP; that bounded by Oy, Oz is the side vertical plane, SVP, and that bounded by Ox and Oz, the horizontal plane, HP, these three planes being the three sides of the box farthest from the observer. Lines are projected, as shown, onto these planes from the object under consideration, and the view obtained when looking at the object in the direction of the arrow A. The end elevation is the view obtained by projection on to the side vertical plane, while the plan is the view obtained by projection on to the horizontal plane. The arrow B shows the direction in which the object is viewed for the side elevation and C the direction for the plan.

Now imagine the sides VP, SVP and HP opened out on their axes Ox, Oy and Oz. The three projections will then be disposed in position, as shown in Fig. 7.1*b*, i.e. the end elevation is to the *right* of the elevation and the plan is *below* the elevation.

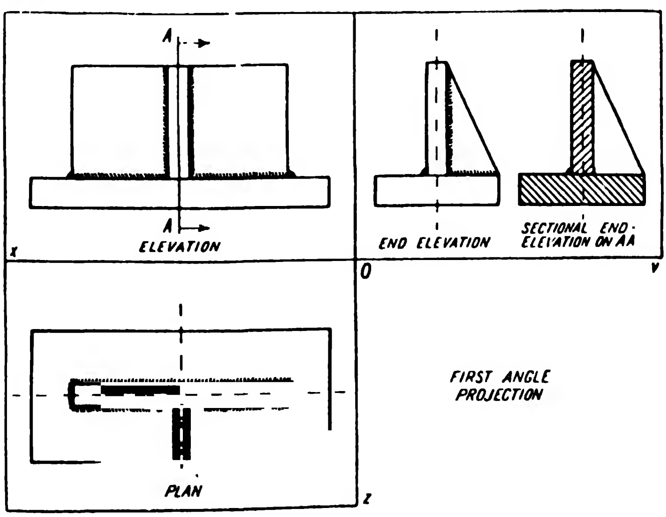
On these three projections, which are those used by the engineer, almost all the details required during manufacture can be included, and hence they are of the greatest importance.

This method is known as First Angle Projection, the projection lines being shown in Fig. 7.1*a*. It is now rarely used

A second method, called Third Angle Projection, is extensively used nowadays, and can be understood by reference to Fig. 7.2*a*.

From this it will be seen that the corner of the box O is chosen to be that nearest the observer, and the three planes are those sides of the box also nearest to the observer, the part under consideration being seen through

Fig 7 1 (*b*)



these planes of projection. The elevation is again that view formed by projection on to the vertical plane Ox, Oy, the end elevation that formed by projection on the side vertical plane Oy, Oz and the plan that formed by projection on the horizontal plane Ox, Oz. Owing, however, to the change in the axes when they are unfolded, the projections are disposed differently, the plan now being *above* the elevation and the side elevation being to the *left* of the elevation (Fig. 7.2*b*). (N.B. The object is viewed in the same direction as previously, as indicated by the arrows.)

Fig. 7 2. (*a*)

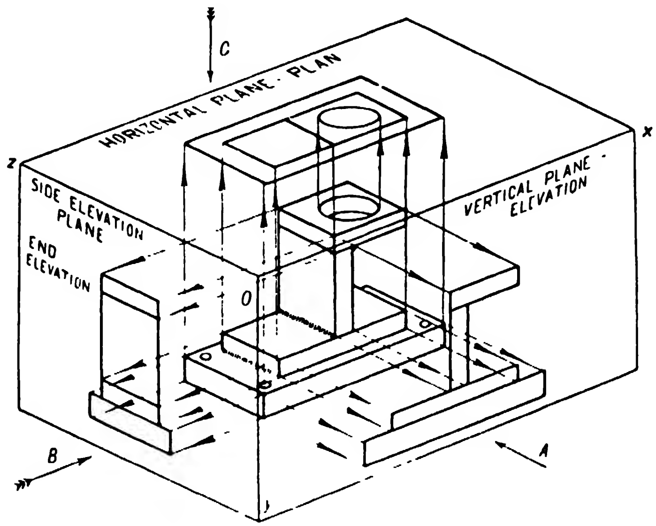
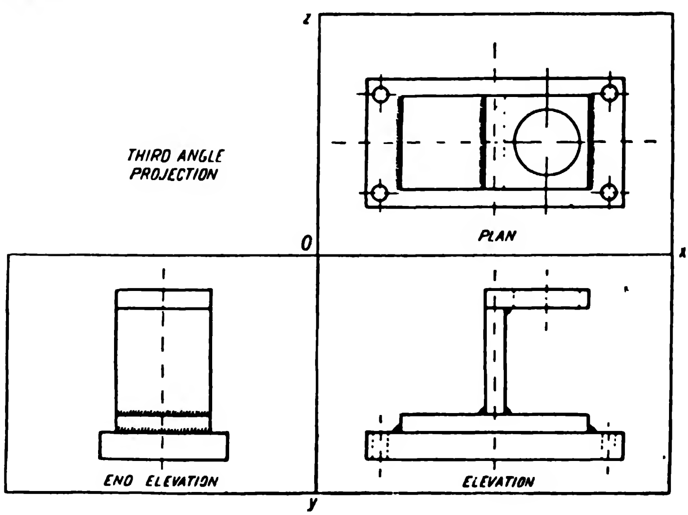


Fig. 7 2. (*b*)



By noting the above difference between the two methods the welder can immediately tell which method has been used. Sometimes a combination of these two methods may be encountered but need not be considered here.

*Welding symbols**

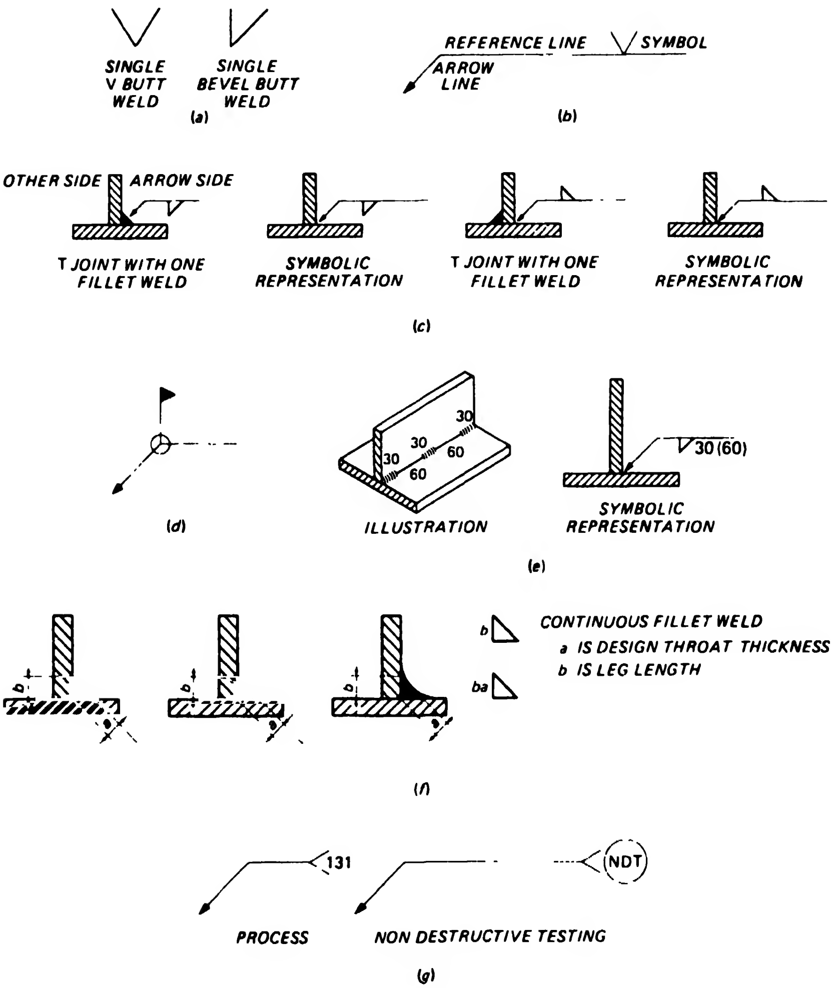
A weld is indicated on a drawing by (1) a symbol (Fig. 7.3*a*) and (2) an arrow connected at an angle to a reference line usually drawn parallel to the bottom of the drawing (Fig. 7.3*b*). The side of the joint on which the arrow is placed is known as the 'arrow side' to differentiate it from the 'other side' (Fig. 7.3*c*). If the weld symbol is placed *below* the reference line, the weld face is on the *arrow-side* of the joint, while if the symbol is above the reference line the weld face is on the other side of the joint (Fig. 7.3*c*). Symbols on both sides of the reference line indicate welds to be made on both sides of the joint, while if the symbol is across the reference line the weld is within the plane of the joint. A circle where arrow line meets reference line indicates that it should be a peripheral (all round) weld, while a blacked in flag at this point denotes an 'on site' weld (Fig. 7.3*d*). Intermittent runs of welding are indicated by figures denoting the welded portions, and figures in brackets the non-welded portions, after the symbol (Fig. 7.3.*e*). A figure before the symbol for a fillet weld indicates the leg length. If the design throat thickness is to be included, the leg length is prefixed with the letter '*b*' and the throat thickness with the letter '*a*'. Unequal leg lengths have a × sign separating the dimensions (Fig. 7.3*f*). A fork at the end of the reference line with a number within it indicates the welding process to be employed (e.g. 131 is MIG, see table on p. 307), while a circle at this point containing the letters NTD indicates that non-destructive testing is required (Fig. 7.3*g*). Weld profiles, flat (or flush), convex and concave profiles are shown as supplementary symbols in Fig. 7.3*h*.

Figure 7.4*a* gives the elementary symbols and 7.4*b* typical uses of them. The student should study BS 499, Part 2, 1980 or later, *Symbols for welding*, for a complete account of this subject.

A table showing the numerical indication of processes complying with International Standard ISO 4063 appears on p. 307.

* BS 499, Part 2, 1980, brings the standard in line with ISO recommendations. See Appendix 4, for American symbols.

Fig. 7.3



Supplementary symbols

SHAPE	SYMBOL
FLAT (USUALLY FINISHED FLUSH)	—
CONVEX	⌒
CONCAVE	‿

Examples of supplementary symbols

DESCRIPTION	ILLUSTRATION	SYMBOL
FLAT (FLUSH) SINGLE V BUTT WELD		
CONVEX DOUBLE V BUTT WELD		
CONCAVE FILLET WELD		
FLAT (FLUSH) SINGLE V BUTT WELD WITH FLAT (FLUSH) BACKING RUN		

*Numerical indication of process (BS 499, Part 2, 1980)**

No.	Process
1	**Arc welding**
11	Metal-arc welding without gas protection
111	Metal-arc welding with covered electrode
112	Gravity arc welding with covered electrode
113	Bare wire metal-arc welding
114	Flux cored metal-arc welding
115	Coated wire metal-arc welding
118	Firecracker welding
12	Submerged arc welding
121	Submerged arc welding with wire electrode
122	Submerged arc welding with strip electrode
13	Gas shielded metal-arc welding
131	MIG welding
135	MAG welding metal-arc welding with non-inert gas shield
136	Flux cored metal-arc welding with non-inert gas shield
14	Gas-shielded welding with non-consumable electrode
141	TIG welding
149	Atomic-hydrogen welding
15	Plasma arc welding
18	Other arc welding processes
181	Carbon arc welding
185	Rotating arc welding
2	**Resistance welding**
21	Spot welding
22	Seam welding
221	Lap seam welding
225	Seam welding with strip
23	Projection welding
24	Flash welding
25	Resistance butt welding
29	Other resistance welding processes
291	HF resistance welding
3	**Gas welding**
31	Oxy-fuel gas welding
311	Oxy-acetylene welding
312	Oxy-propane welding
313	Oxy-hydrogen welding
32	Air fuel gas welding
321	Air-acetylene welding
322	Air-propane welding
4	**Solid phase welding; Pressure welding**
41	Ultrasonic welding
42	Friction welding
43	Forge welding
44	Welding by high mechanical energy
441	Explosive welding
45	Diffusion welding
47	Gas pressure welding
48	Cold welding
7	**Other welding processes**
71	Thermit welding
72	Electroslag welding
73	Electrogas welding
74	Induction welding
75	Light radiation welding
751	Laser welding
752	Arc image welding
753	Infrared welding
76	Electron beam welding
77	Percussion welding
78	Stud welding
781	Arc stud welding
782	Resistance stud welding
9	**Brazing, soldering and braze welding**
91	Brazing
911	Infrared brazing
912	Flame brazing
913	Furnace brazing
914	Dip brazing
915	Salt bath brazing
916	Induction brazing
917	Ultrasonic brazing
918	Resistance brazing
919	Diffusion brazing
923	Friction brazing
924	Vacuum brazing
93	Other brazing processes
94	Soldering
941	Infrared soldering
942	Flame soldering
943	Furnace soldering
944	Dip soldering
945	Salt bath soldering
946	Induction soldering
947	Ultrasonic soldering
948	Resistance soldering
949	Diffusion soldering
951	Flow soldering
952	Soldering with soldering iron
953	Friction soldering
954	Vacuum soldering
96	Other soldering processes
97	Braze welding
971	Gas braze welding
972	Arc braze welding

This table complies with International Standard ISO 4063.

Fig. 7.4. (*a*) Elementary welding symbols (BS 499, Part 2, 1980)

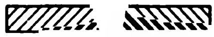
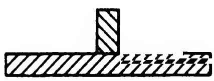
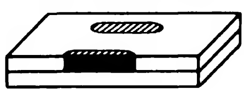
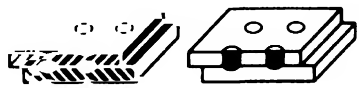
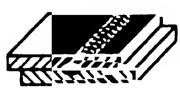
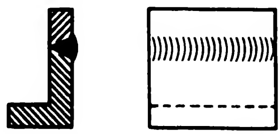
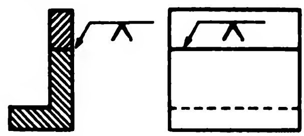
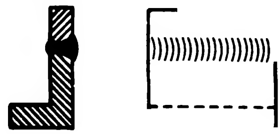
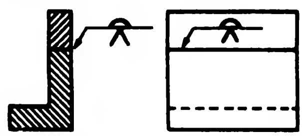
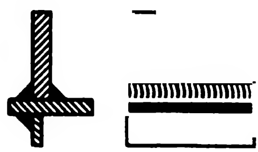
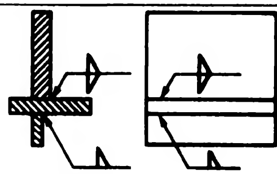
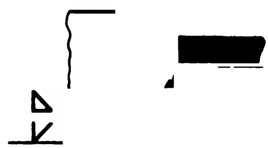
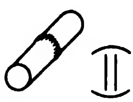
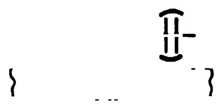
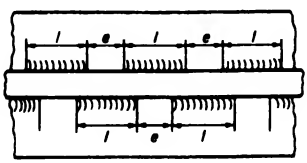
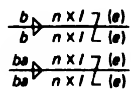
DESCRIPTION	SECTIONAL REPRESENTATION	SYMBOL
1. BUTT WELD BETWEEN FLANGED PLATES (FLANGES MELTED DOWN COMPLETELY)		
2. SQUARE BUTT WELD		
3. SINGLE-V BUTT WELD		
4. SINGLE-BEVEL BUTT WELD		
5. SINGLE-V BUTT WELD WITH BROAD ROOT FACE		
6. SINGLE-BEVEL BUTT WELD WITH BROAD ROOT FACE		
7. SINGLE-U BUTT WELD		
8. SINGLE-J BUTT WELD		
9. BACKING OR SEALING RUN		
10. FILLET WELD		
11. PLUG WELD (CIRCULAR OR ELONGATED HOLE, COMPLETELY FILLED)	ILLUSTRATION 	
12. SPOT WELD (RESISTANCE OR ARC WELDING) OR PROJECTION WELD	 (a) RESISTANCE (b) ARC	
13. SEAM WELD		

Fig. 7.4. (*b*) Examples of uses of symbols (BS 499, Part 2, 1980).

DESCRIPTION SYMBOL	GRAPHIC REPRESENTATION	SYMBOLIC REPRESENTATION
SINGLE V BUTT WELD		
SINGLE-V BUTT WELD AND BACKING RUN		
FILLET WELD		
SINGLE-BEVEL BUTT WELD WITH FILLET WELD SUPERIMPOSED		
SQUARE BUTT WELD 		
STAGGERED INTERMITTENT FILLET WELD		 *a* IS THE DESIGN THROAT THICKNESS *b* IS THE LEG LENGTH *e* IS THE DISTANCE BETWEEN ADJACENT WELD ELEMENTS *l* IS THE LENGTH OF THE WELD (WITHOUT END CRATERS) *n* IS THE NUMBER OF WELD ELEMENTS

See Appendix 4, for American symbols

Appendix 1

Tables of elements and conversions

Elements: their symbols, atomic weights and melting points.

Element	Symbol	Atomic weight	Melting point (°C)
Actinium	Ac	227	—
Aluminium	Al	26.97	658.7
Americium	Am	241	—
Antimony	Sb	121.77	630
Argon	Ar	39.94	– 188
Arsenic	As	74.96	850
Astatine	At	211	—
Barium	Ba	137.36	850
Berkelium	Bk	245	—
Beryllium	Be	9.02	1280
Bismuth	Bi	209.00	271
Boron	B	10.82	2200–2500
Bromine	Br	79.91	– 7.3
Cadmium	Cd	112.41	320.9
Caesium	Cs	132.81	26
Calcium	Ca	40.07	810.0
Californium	Cf	246	..
Carbon	C	12.00	3600
Cerium	Ce	140.13	635
Chlorine	Cl	35.45	– 101.5
Chromium	Cr	52.01	1615
Cobalt	Co	58.94	1480
Copper	Cu	63.57	1083
Curium	Cm	242	—
Dysprosium	Dy	162.5	—
Erbium	Er	167.64	—
Europium	Eu	152	—
Fluorine	F	19.0	– 223
Francium	Fa	223	—
Gadolinium	Gd	157.26	—

Elements: their symbols, atomic weights and melting points (contd.)

Element	Symbol	Atomic weight	Melting point (°C)
Gallium	Ga	69.72	30.1
Germanium	Ge	72.60	958
Gold	Au	197.2	1063
Hafnium	Hf	179	2200
Helium	He	4.00	−272
Holmium	Ho	165	—
Hydrogen	H	1.0078	−259
Indium	In	114.8	155
Iodine	I	126.932	113.5
Iridium	Ir	193.1	2350
Iron	Fe	55.84	1530
Krypton	Kr	83.7	−169
Lanthanum	La	138.90	810
Lead	Pb	207.22	327.4
Lithium	Li	6.94	186
Lutecium	Lu	175	—
Magnesium	Mg	24.32	651
Manganese	Mn	54.93	1230
Mercury	Hg	200.61	−38.87
Molybdenum	Mo	96	2620
Neodymium	Nd	144.27	840
Neon	Ne	20.18	−253
Neptunium	Np	237	—
Nickel	Ni	58.69	1452
Niobium (Columbium)	Nb(Cb)	92.9	1950
Nitrogen	N	14.008	−210
Osmium	Os	190.8	2700
Oxygen	O	16.000	−218
Palladium	Pd	106.7	1549
Phosphorus	P	30.98	44
Platinum	Pt	195.23	1755
Plutonium	Pn	239	—
Polonium	Po	210	—
Potassium	K	39.1	62.3
Praseodymium	Pr	140.92	940
Promethium	Pm	147	—
Protactinium	Pa	231	—
Radon	Rn	222	−71
Radium	Ra	226.1	700
Rhenium	Re	186	3167
Rhodium	Rh	102.91	1950
Rubidium	Rb	85.44	38
Ruthenium	Ru	101.7	2450
Samarium	Sm	150.43	1300–1400
Scandium	Sc	45.10	1200
Selenium	Se	78.96	217–220

Elements: their symbols, atomic weights and melting points (contd.)

Element	Symbol	Atomic weight	Melting point (°C)
Silicon	Si	28.06	1420
Silver	Ag	107.88	960.5
Sodium	Na	22.997	97.5
Strontium	Sr	87.63	800
Sulphur	S	32.06	112.8
Tantalum	Ta	181.5	2900
Technetium	Tc	99	—
Tellurium	Te	127.5	452
Terbium	Tb	159.2	—
Thallium	Tl	204.39	302
Thorium	Th	232.12	1700
Tin	Sn	118.70	231.9
Thulium	Tm	169.4	—
Titanium	Ti	47.9	1800
Tungsten	W	184.0	3400
Uranium	U	238.14	1850
Vanadium	V	50.96	1720
Xenon	Xe	131.3	−140
Ytterbium	Yb	173.6	1800
Yttrium	Y	88.92	1490
Zinc	Zn	65.38	419.4
Zirconium	Zr	91.22	1700

Gauge table. Imperial standard

No.	Size (in)	Size (mm)
0	0.324	8.229
1	0.300	7.620
2	0.276	7.010
3	0.252	6.401
4	0.232	5.893
5	0.212	5.385
6	0.192	4.877
7	0.176	4.470
8	0.160	4.064
9	0.144	3.658
10	0.128 approx. $\frac{1}{8}$ in	3.251
11	0.116	2.946
12	0.104	2.642
13	0.092	2.337
14	0.080	2.032
15	0.072	1.829
16	0.064 approx. $\frac{1}{16}$ in	1.626
17	0.056	1.422

Gauge table. Imperial standard (contd.)

No.	Size (in)	Size (mm)
18	0.048	1.219
19	0.040	1.016
20	0.036	0.914
21	0.032 approx. $\frac{1}{32}$ in	0.813
22	0.028	0.711
23	0.024	0.610
24	0.022	0.559
25	0.020	0.508
26	0.018	0.457
27	0.0164	0.4166
28	0.0148	0.3759
29	0.0136	0.3454
30	0.0124	0.315

Millimetres to inches

mm	in 0	1	2	3	4	5	6	7	8	9
0	---	0 03937	0 07874	0 11811	0 15748	0 19685	0 23622	0 27559	0 31496	0 35433
10	0 39370	0 43307	0 47244	0 51181	0 55118	0 59055	0 62992	0 66929	0 70866	0 74803
20	0 78740	0 82677	0 86614	0 90551	0 94488	0 98425	1 02362	1 06299	1 10236	1 14173
30	1 18110	1 22047	1 25984	1 29921	1 33858	1 37795	1 41732	1 45669	1 49606	1 53543
40	1 57480	1 61417	1 65354	1 69291	1 73228	1 77165	1 81102	1 85039	1 88976	1 92913
50	1 96850	2 00787	2 04724	2 08661	2 12598	2 16535	2 20472	2 24409	2 28346	2 32283
60	2 36220	2 40157	2 44094	2 48031	2 51969	2 55906	2 59843	2 63780	2 67717	2 71654
70	2 75591	2 79528	2 83465	2 87402	2 91339	2 95276	2 99213	3 03150	3 07087	3 11024
80	3 14961	3 18898	3 22835	3 26772	3 30709	3 34646	3 38573	3 42520	3 46457	3 50394
90	3 54331	3 58268	3 62205	3 66142	3 70079	3 74016	3 77953	3 81890	3 85827	3 89764
100	3 93701	3 97638	4 01575	4 05512	4 09449	4 13386	4 17323	4 21260	4 25197	4 29134
110	4 33071	4 37008	4 40945	4 44882	4 48819	4 52756	4 56693	4 60630	4 64567	4 68504
120	4 72441	4 76378	4 80315	4 84252	4 88189	4 92146	4 96063	5 00000	5 03937	5 07874
130	5 11811	5 15748	5 19685	5 23622	5 27559	5 31496	5 35433	5 39370	5 43307	5 47244
140	5 51181	5 55118	5 59055	5 62992	5 66929	5 70866	5 74803	5 78740	5 82677	5 86614
150	5 90551	5 94488	5 98425	6 02362	6 06229	6 10236	6 14173	6 18110	6 22047	6 25984
160	6 29921	6 33858	6 37795	6 41732	6 45669	6 49606	6 53543	6 57480	6 61417	6 65354
170	6 69291	6 73228	6 77165	6 81102	6 85039	6 88976	6 92913	6 96850	7 00787	7 04724
180	7 08661	7 12598	7 16535	7 20472	7 24409	7 28346	7 32283	7 36220	7 40157	7 44094
190	7 48031	7 51969	7 55906	7 59843	7 63780	7 67717	7 71654	7 75591	7 79528	7 83465
200	7 87402	7 91339	7 95276	7 99213	8 03150	8 07087	8 11024	8 14961	8 18898	8 22835
210	8 26772	8 30709	8 34646	8 38583	8 42520	8 46457	8 50394	8 54331	8 58268	8 62205
220	8 66142	8 70079	8 74016	8 77953	8 81890	8 85827	8 89764	8 93701	8 97638	9 01575
230	9 05512	9 09449	9 13386	9 17323	9 21260	9 25197	9 29134	9 33071	9 37008	9 40945
240	9 44882	9 48819	9 52756	9 56693	9 60630	9 64567	9 68504	9 72441	9 76378	9 80315

Thousandths of an inch to millimetres

					mm					
Mils*	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	—	0 0254	0.0508	0.0762	0 1016	0.1270	0.1524	0 1778	0 2032	0.2286
10	0.2540	0 2794	0 3048	0.3302	0 3556	0 3810	0.4064	0 4318	0 4572	0.4826
20	0 5080	0 5334	0.5588	0 5842	0.6096	0 6350	0.6604	0.6858	0.7112	0.7366
30	0 7620	0 7874	0 8128	0 8382	0 8636	0.8890	0.9144	0 9398	0 9652	0.9906
40	1 0160	1 0414	1.0668	1.0922	1 1176	1 1430	1.1684	1 1938	1.2192	1.2446
50	1 2700	1 2954	1.3208	1 3462	1 3716	1.3970	1.4224	1 4478	1 4732	1 4986
60	1 5240	1 5494	1.5748	1 6002	1 6256	1.6510	1 6764	1 7018	1 7272	1 7526
70	1 7780	1 8034	1 8288	1 8542	1 8796	1.9050	1.9304	1 9558	1 9812	2.0066
80	2 0320	2 0574	2 0828	2 1082	2 1336	2.1590	2.1844	2.2098	2 2352	2 2606
90	2 2860	2 3114	2 3368	2 3622	2 3876	2 4130	2 4384	2 4638	2 4892	2 5146
100	2 5400	2 5654	2 5908	2.6162	2 6416	2 6670	2.6924	2 7178	2 7432	2 7686
110	2 7940	2.8194	2 8448	2 8702	2 8956	2 9210	2.9464	2 9718	2.9972	3.0226
120	3 0480	3 0734	3.0988	3.1242	3 1496	3 1750	3.2004	3 2258	3 2512	3 2766
130	3 3020	3 3274	3 3528	3.3782	3.4036	3 4290	3.4544	3.4798	3 5052	3 5306
140	3 5560	3 5814	3 6068	3 6322	3 6576	3 6830	3.7084	3 7338	3 7592	3.7846
150	3,8100	3 8354	3.8608	3 8862	3 9116	3 9370	3 9624	3 9878	4 0132	4 0386
160	4 0640	4.0894	4 1148	4 1402	4 1656	4 1910	4 2164	4 2418	4 2672	4.2926
170	4 3180	4 3434	4 3688	4.3942	4 4196	4 4450	4 4704	4 4958	4 5121	4 5466
180	4 5720	4 5974	4 6228	4.6482	4 6736	4 6990	4.7244	4 7498	4 7752	4 8006
190	4 8260	4 8514	4 8768	4 9022	4 9276	4 9530	4.9784	5 0038	5 0292	5 0546
200	5 0800	5 1054	5 1308	5 1562	5 1816	5 2070	5 2324	5.2578	5 2832	5 3086
210	5.3340	5 3594	5 3848	5 4102	5 4356	5 4610	5 4864	5 5118	5 5372	5 5626
220	5 5880	5 6134	5 6388	5 6642	5.6896	5 7150	5 7404	5 7658	5 7912	5 8166
230	5 8420	5 8674	5 8928	5 9182	5 9436	5 9690	5 9944	6 0198	6 0452	6 0706
240	6 0960	6 1214	6 1468	6 1722	6.1976	6 2230	6 2484	6 2738	6 2992	6 3246
250	6 3500	6 3754	6 4008	6 4262	6 4516	6 4770	6 5024	6 5278	6 5532	6 5786
260	6 6040	6 6294	6 6548	6 6802	6 7056	6 7310	6 7564	6 7818	6 8072	6 8326
270	6 8580	6 8834	6 9088	6 9342	6 9596	6.9850	7 0104	7 0358	7 0612	7 0866
280	7 1120	7 1374	7 1628	7 1882	7 2136	7 2390	7 2644	7 2898	7 3152	7 3406
290	7 3660	7 3914	7 4168	7 4422	7 4676	7 4930	7 5184	7.5483	7 5692	7 5946
300	7 6200	7 6454	7 6708	7 6962	7 7216	7 7470	7 7724	7 7978	7 8232	7 8486
310	7 8740	7 8994	7 9248	7 9502	7 9756	8 0010	8 0264	8 0518	8 0772	8 1026
320	8 1280	8 1534	8 1788	8 2042	8 2296	8 2550	8 2804	8 3058	8 3312	8 3566
330	8 3820	8 4074	8 4328	8 4582	8 4836	8 5090	8 5344	8 5598	8 5852	8 6106
340	8 6360	8 6614	8 6868	8 7122	8 7376	8 7630	8 7884	8 8138	8 8392	8 8646
350	8 8900	8 9154	8 9408	8 9662	8 9916	9 0170	9 0424	9 0678	9 0932	9 1186
360	9 1440	9 1694	9 1948	9 2202	9 2456	9 2710	9 2964	9 3218	9 3472	9 3726
370	9 3980	9 4234	9 4488	9 4742	9 4996	9 5250	9 5504	9 5758	9 6012	9.6266
380	9 6520	9 6774	9 7028	9 7282	9 7536	9 7790	9 8044	9 8298	9 8552	9 8806
390	9 9060	9 9314	9 9568	9.9822	10 0076	10 0330	10 0584	10 0838	10 1092	10 1346

* 1 Mil = 0 001 inch

hbar to tonf/in², MN/m², lbf/in² and kgf/mm²

h bar	tonf/in²	MN/m² N/mm²	lbf/in²	kgf/mm²	hbar	tonf/in²	MN/m² N/mm²	lbf/in²	kgf/mm²
0 5	0 3	5	700	0 5	30 5	19 7	305	44200	31 1
1	0 6	10	1500	1 0	31	20 1	310	45000	31 6
1 5	1 0	15	2200	1 5	31 5	20 4	315	45700	32 1
2	1 3	20	2900	2 0	32	20 7	320	46400	32.6
2 5	1.6	25	3600	2 5	32 5	21 0	325	47100	33 1
3	1 9	30	4400	3 1	33	21 4	330	47900	33 7
3 5	2 3	35	5100	3 6	33 5	21 7	335	48600	34 2
4	2 6	40	5800	4 1	34	22 0	340	49300	34 7
4 5	2 9	45	6500	4 6	34 5	22 3	345	50000	35 2
5	3 2	50	7300	5 1	35	22 7	350	50800	35 7
5 5	3 6	55	8000	5 6	35 5	23 0	355	51500	36 2
6	3 9	60	8700	6 1	36	23 3	360	52200	36 7
6 5	4 2	65	9400	6 6	36 5	23 6	365	52900	37 2
7	4 5	70	10200	7 1	37	24 0	370	53700	37 7
7 5	4 9	75	10900	7 6	37 5	24 3	375	54400	38 2
8	5 2	80	11600	8 2	38	24 6	380	55100	38 7
8 5	5 5	85	12300	8 7	38 5	24 9	385	55800	39 3
9	5 8	90	13100	9 2	39	25 3	390	56600	39 8
9 5	6 2	95	13800	9 7	39 5	25 6	395	57300	40 3
10	6 5	100	14500	10 2	40	25 9	400	58000	40 8
10 5	6 8	105	15200	10 7	40 5	26 2	405	58700	41 3
11	7 1	110	16000	11 2	41	26 5	410	59500	41 8
11 5	7 4	115	16700	11 7	41 5	26 9	415	60200	42 3
12	7 8	120	17400	12 2	42	27 2	420	60900	42 8
12 5	8 1	125	18100	12 7	42 5	27 5	425	61600	43 3
13	8 4	130	18900	13 3	43	27 8	430	62400	43 8
13 5	8 7	135	19600	13 8	43 5	28 2	435	63100	44 4
14	9 1	140	20300	14 3	44	28 5	440	63800	44 9
14 5	9 4	145	21000	14 8	44 5	28 8	445	64500	45 4
15	9 7	150	21800	15.3	45	29 1	450	65300	45 9
15 5	10 0	155	22500	15 8	45 5	29 5	455	66000	46 4
16	10 4	160	23200	16 3	46	29 8	460	66700	46 9
16 5	10 7	165	23900	16 8	46 5	30 1	465	67400	47 4
17	11 0	170	24700	17 3	47	30 4	470	68200	47 9
17 5	11 3	175	25400	17 8	47 5	30 8	475	68900	48 4
18	11 7	180	26100	18 4	48	31 1	480	69600	48 9
18 5	12 0	185	26800	18 9	48 5	31 4	485	70300	49 5
19	12 3	190	27600	19 4	49	31 7	490	71100	50 0
19 5	12 6	195	28300	19 9	49 5	32 1	495	71800	50 5
20	12 9	200	29000	20 4	50	32 4	500	72500	51 0
20 5	13 3	205	29700	20 9	50 5	32 7	505	73200	51 5
21	13 6	210	30500	21 4	51	33 0	510	74000	52 0
21 5	13 9	215	31200	21 9	51 5	33 3	515	74700	52 5
22	14 2	220	31900	22 4	52	33 7	520	75400	53 0
22 5	14 6	225	32600	22 9	52 5	34 0	525	76100	53 5
23	14 9	230	33400	23 5	53	34 3	530	76900	54 0
23 5	15 2	235	34100	24 0	53 5	34 6	535	77600	54 6
24	15 5	240	34800	24 5	54	35 0	540	78300	55 1
24 5	15 9	245	35500	25 0	54 5	35 3	545	79000	55 6
25	16 2	250	36300	25 5	55	35 6	550	79800	56 7
25 5	16 5	255	37000	26 0	55 5	35 9	555	80500	56 6
26	16 8	260	37700	26 5	56	36 3	560	81200	57 1
26 5	17 2	265	38400	27 0	56 5	36 6	565	81900	57 6
27	17 5	270	39200	27 5	57	36 9	570	82700	58 1
27 5	17 8	275	39900	28 0	57 5	37 2	575	83400	58 6
28	18 1	280	40600	28 6	58	37 6	580	84100	59 1
28 5	18 5	285	41300	29 1	58 5	37 9	585	84800	59 7
29	18 8	290	42100	29 6	59	38 2	590	85600	60 2
29 5	19 1	295	42800	30 1	59 5	38 5	595	86300	60 7
30	19 4	300	43500	30 6	60	38 8	600	87000	61 2

Factors

To convert	Multiply by	To convert	Multiply by
in to mm	25.4	mm to in	0 03937
in^2 to mm^2	645 16	mm^2 to in^2	0 00155
in^3 to cm^3	16 387	cm^3 to in^3	0 061024
in^4 to cm^4	41.623	cm^4 to in^4	0.024025
ft to m	0 3048	m to ft	3 2808
ft^2 to m^2	0 092903	m^2 to ft^2	10 764
ft^3 to m^3	0 028317	m^3 to ft^3	35 315
yd to m	0 9144	m to yd	1 0936
yd^2 to m^2	0 83613	m^2 to yd^2	1.1960
yd^3 to m^3	0 76456	m^3 to yd^3	1.3080
lb to kg	0 45359	kg to lb	2 2046
cwt to kg	50 802	kg to cwt	0.019684
tons to kg	1016 1	kg to tons	0 00098421
tons to lb	2240	lb to tons	0 0004464
tons to short tons	1 12	short tons to tons	0 8929
tons to tonnes (metric)	1.0160	tonnes (metric) to tons	0 98421
lb/in^2 to kg/mm^2	0 0007031	kg/mm^2 to lb/in^2	1422 33
lb/in^2 to kg/cm^2	0 07031	kg/cm^2 to lb/in^2	14 2233
lb/in^2 to $tons/in^2$	0 0004464	$tons/in^2$ to lb/in^2	2240
lb/in^3 to g/cm^3	27 680	g/cm^3 to lb/in^3	0 036127
lb/ft to kg/m	1 4882	kg/m to lb/ft	0 67197
lb/ft^2 to kg/m^2	4 8824	kg/m^2 to lb/ft^2	0 2048
$tonf/in^2$ to MN/m^2 or MPa or N/mm^2	15 444	MPa or MN/m^2 to $tonf/in^2$	0 064749
$tonf/in^2$ to hbar	1 5444	hbar to $tonf/in^2$	0 64749
$tonf/in^2$ to kgf/mm^2	1 5749	kgf/mm^2 to $tonf/in^2$	0 63497
lbf/ft^2 to N/m^2 or Pa	47 880	Pa or N/m^2 to lbf/ft^2	0 02089
lbf/in^2 to N/m^2 or Pa	6894 8	Pa or N/m^2 to lbf/in^2	0 00014504
lbf/in^2 to hbar or Pa	0 00068948	hbar to lbf/in^2	1450 4
kgf/m^2 to N/m^2 or Pa	9 8067	Pa or N/m^2 to kgf/m^2	0 10197
kgf/mm^2 to hbar	0 98067	hbar to kgf/mm^2	1 0197
cal cm/cm^2 s °C to W/m °C	418 68	W/m °C to cal cm/cm^2 s °C	0 00238885
$\mu\Omega$ m to Ω m	10^{-6}	Ω m to $\mu\Omega$ cm	10^{8}

Other conversions

	Multiply by
Density	
Pounds/cubic inch to kilograms/cubic metre	27680
Pounds/cubic foot to kilograms/cubic metre	16 018
Tons/cubic yard to kilograms/cubic metre	1328 9
Force	
Poundals to newtons	0 13825
Pounds force to newtons	4 448
Tons force to newtons	9964
Torque	
Pounds force-inch to newton-metres	0.11298
Pounds force-feet to newton-metres	1.3558
Tons force-feet to newton-metres	3037
Inches of mercury to millibars	33.864
Inches of mercury to newtons per square metre or pascal	3386.4

Note. 1 bar = 10^5 newtons per square metre or 10 Pa

Work, Energy	
Therms to mega-joules	105.5
Kilowatt-hours to mega-joules	3.6
British thermal unit to joules (metre-newtons)	1055.1
Centigrade heat unit to joules (metre-newtons)	1899.2
Foot pound f. to joules (metre-newtons)	1 3558
Power	
Horse-power to watts (joules per sec)	745.7
Foot pound f. per sec to watts (joules per sec)	1.3558
Illumination	
Lumens per square foot / Foot candles } to lumens per square metre (lux)	10.764
Angular measurement	
Radians to degree	57.29
Degrees to radians	0.01745

Appendix 2

Selection of British Standards relating to welding

Note. When consulting British Standards the engineer should make sure that the Standard concerned incorporates the latest amendments.

See also notes on acceptance levels for defects in fusion welded joints, PD 6493

	BS number
Welding terms and symbols	*499*
Part 1 Glossary for welding, brazing and thermal cutting	
Part 2 Symbols for welding	
Part 2C Chart giving type, position and method of representation of welding symbols and their uses	
Arc welding plant, equipment and accessories	*638*
Part 1 Oil-cooled power sources for manual, semi-automatic and automatic metal arc welding and for TIG welding	
Part 2 Air-cooled power sources for manual metal arc with covered electrodes and for TIG welding	
Part 3 Air-cooled power sources for semi-automatic and automatic metal arc welding	
Part 4 Welding cables	
Part 6 Safety requirements for construction	
Part 7 Safety requirements for installation and use	
Part 8 Electrode holders and hand-held torches and guns for MIG, MAG and TIG welding	
Covered carbon and carbon manganese steel electrodes for manual metal arc welding	*639*

Code of practice for training in arc welding skills (covers MMA, MIG, MAG and TIG skills)	*1295*
Low-alloy steel electrodes for manual metal arc welding	*2493*
Chromium and chromium–nickel steel electrodes for MMA welding	*2926*
Class I arc welding of ferritic steel pipework for carrying fluids	*2633*
Arc welding of austenitic stainless steel pipework for carrying fluids	*4677*
Class II arc welding of carbon steel pipework for carrying fluids	*2971*
Welding of steel pipelines on or off shore	*4515*
Arc welding of carbon and carbon manganese steels	*5135*
Electrode wires and fluxes for the submerged arc welding of carbon steel and medium tensile steel	*4165*
Electrode and fluxes for submerged arc welding of austenitic stainless steel	*5465*
TIG welding *Part 1 TIG welding of aluminium, magnesium and their alloys* *Part 2 Austenitic stainless and heat-resisting steels*	*3019*
MIG welding *MIG welding of aluminium and aluminium alloys*	*3571*
Filler rods and wires for gas shielded arc welding *Part 1 Ferritic steels* *Part 2 Austenitic stainless steels* *Part 3 Copper and copper alloys* *Part 4 Aluminium and aluminium alloys and magnesium alloys* *Part 5 Nickel and nickel alloys*	*2901*
Wrought aluminium and aluminium alloys for general engineering purposes (materials used as welding wire)	*1475*
Welded steel boilers for central heating and indirect hot water supply, 44 kW to 3 MW	*855*
Steel butt-welding pipe fittings for the petroleum industry *Part 1 Wrought carbon and ferritic alloy steel fittings* *Part 2 Wrought and cast austenitic chromium nickel steel fittings* *Part 3 Wrought carbon and ferritic alloy steel fittings (metric units)* *Part 4 Wrought and cast austenitic chromium nickel steel fittings (metric units)*	*1640*
Butt welding pipe fittings for pressure purposes *Part 1 Carbon steel*	*1965*
Manufacture of vertical steel-welded storage tanks with butt-welded shells for the petroleum industry	*2654*
Small fusion-welded air reservoirs for road and railway vehicles	*3256*
Design and manufacture of shell boilers of welded construction	*2790*
Vertical cylindrical welded steel storage tanks for low-temperature service: single-wall tanks for temperatures down to −50 °C	*4741*
Weldable structural steels	*4360**

* Note that the new European steel standards are indicated by the prefix BSEN (e g BS 4360 becomes BSEN 1025 and in Germany DINEN 1025)

Transportable gas containers: 5045
Part 2 Steel containers up to 130 litres water capacity, welded seams
Part 5 Aluminium alloy containers above 0.5 litre up to 130 litres water capacity with welded seams.

Unfired fusion-welded pressure vessels 5500

Method of determination of ferrite number in austenitic weld metal deposited by covered chromium-nickel 6787

Method for the determining of the austenitic grain size of steel (appendix gives etching reagents) 4490

Pressure regulators used in welding, cutting and related processes 5741

Testing

Methods of testing fusion welds in copper and copper alloys 4206

Methods of testing fusion welds in aluminium and aluminium alloys 3451

Methods of destructive testing fusion welded joints and weld metal in steel 709

Method for magnetic particle flaw detection 6072

Method for penetrant flaw detection 6443

Methods for ultrasonic examination of welds: 3923
Part 1 Manual examination of fusion welds in ferritic steels
Part 2 Automatic examination of fusion welded butt joints in ferritic steels

Method for Brinell hardness test (up to 600 HB) and for verification of Brinell hardness testing machine 240

Method for Rockwell hardness test 891
Part 1 Testing of metals (scales A to K inclusive)
Part 2 Verification of the testing machine

Method for Vickers hardness test. 427
Part 1 Testing of metals
Part 2 Verification of testing machine

Glossary of terms used in non-destructive testing 3683
Part 1 Penetrant flaw detection
Part 2 Magnetic particle flaw detection
Part 3 Radiological flaw detection
Part 4 Ultrasonic flaw detection
Part 5 Eddy current flaw detection

Diffusible hydrogen 6693
Part 1 Method of determination of hydrogen in MMA weld metal using 3-day collection
Part 2 Method of determination of hydrogen in MMA weld metal

Methods for radiographic examination of fusion welded circumferential butt joints in steel pipes 2910

Radiographic examination of fusion welded butt joints in steel 2600
Part 1 Methods for steel 2 mm up to and including 50 mm thick
Part 2 Methods for steel over 50 mm up to and including 200 mm thick

Methods for crack opening displacement (COD), crack tip opening displacement (CTOD) 5762

Code of practice. Visual inspection of fusion welded joints 5289

Approval testing of welding procedures: 4870
Part 1 Fusion welding of steel
Part 2 TIG or MIG welding of aluminium and its alloys
Part 3 Arc welding of tube to tube plate joints in metallic materials

Approval testing of welders working to approved welding procedures: 4871
Part 1 Fusion welding of steel
Part 2 TIG or MIG welding of aluminium and its alloys
Part 3 Arc welding of tube to tube plate joints in metallic materials

Approval testing of welders when welding procedure approval is not required: 4872
Part 1 Fusion welding of steel
Part 2 TIG or MIG welding of aluminium and its alloys

Guide to macroscopic examination of steel by etching with strong mineral acid 6533

Methods for notched bar tests: 131
Part 1 Izod impact test of metals
Part 2 Charpy V notch impact test on metals
Part 3 Charpy U notch impact test on metals
Part 4 Calibration of pendulum impact testing machine
Part 5 Determination of crystallinity

Spot and seam welding

Resistance spot welding of uncoated and coated low carbon steel 1140

Resistance projection welding of uncoated low carbon steel sheet and strip using embossed projections 2630

Resistance seam welding of uncoated and coated low carbon steel 6265

Flash welding of steel tubes for pressure applications 4204

Spot welding electrodes and eletrode holders 4215

Spot welding electrodes 807

Safety

Identification of contents of industrial gas containers (marking and colour) 349

Identification of contents of industrial gas cylinders (colour chart etc.) 349C

Equipment for eye, face and neck protection against non-ionizing radiation arising during welding and similar operations 1542

Filters for use during welding and similar industrial operations 679

Protective clothing for welders 2653

Flameproof industrial clothing (materials and design) 1547

Industrial gloves 1651

Safety footwear 1870
Part 1 Safety footwear other than all-rubber and all-plastics moulded types
Part 2 Lined rubber safety boots (including toe caps)
Part 3 Polyvinyl chloride moulded safety footwear

Workwear	*5426*
Industrial eye protection (not radiation)	*2092*
Safety signs and colours: *Part 1 Colour and design* *Part 2 Colorimetric and photometric properties of materials* *Part 3 Additional signs to those given in part 1*	*5378*
Safety requirements for electrical equipment for machines for resistance welding and allied processes	*5924*
Safety devices for fuel gases and oxygen or compressed air for welding, cutting and related processes	*6158*
Fumes from welding and allied processes: *Part 1 Guide to methods for the sampling and analysis of particulate matter* *Part 2 Guide to the method for the sampling and analysis of gases*	*6691*

Gas welding

Filler materials for gas welding (ferritic steels, cast iron, austenitic stainless steels, copper and copper alloys, aluminium and its alloys, magnesium alloys	*1453*
Bronze welding by gas	*1724*
Class I oxy-acetylene welding of ferritic steel pipework for carrying fluids	*1821*
Class II oxy-acetylene welding of carbon steel pipework for carrying fluids	*2640*
Brazing: *Part 1 Requirements for brazing* *Part 2 Guide to brazing*	*1723*
Filler metals for brazing	*1845*
Hose connections and hose assemblies for equipment for gas welding, cutting and related processes	*1389*

Note. ANSI = American National Standards Institute.
ASTM = American Society for Testing and Materials.
ASME = American Society of Mechanical Engineers.

Appendix 3

Notes on Published Document (PD) 6493 of the British Standards 1: Guidance on some methods for the derivation of acceptance levels for defects in fusion welded joints

Choice of parent plate and weld metal can be made after tensile, compression, fatigue, impact and hardness etc. tests are made and, when a welded structure or component is completed, NDT tests (X- or gamma-ray, magnetic, ultrasonic etc.) are employed to determine the presence of various defects which may cause failure in service. These defects may be divided into planar and non-planar:

Planar defects

(*a*) cracks
(*b*) lack of fusion or penetration
(*c*) undercut, root undercut or concavity and overlap

Non-planar defects

(*a*) cavities
(*b*) solid inclusions

Methods of failure

(*a*) brittle fracture
(*b*) fatigue
(*c*) overload of the remaining cross-section
(*d*) leakage in vessels
(*e*) corrosion, erosion, corrosion fatigue, stress corrosion
(*f*) buckling
(*g*) creep or interaction between creep and fatigue

From a study of PD 6493 it will be seen that some of these defects may be acceptable whilst others are not. These latter must be rectified otherwise there is a risk of failure. All of this is subject to agreement between interested parties.

If defects do not exceed quality control level, there need not be any further action.

If acceptance levels have been agreed upon based on the Engineering Critical Assessment (ECA) for materials used, welding consumables and processes, welding procedure and any stress factors due to wind, water etc. defects should be assessed on this base.

If no acceptance levels have been agreed upon, an ECA based on the guidance given in PD 6493 or an agreed alternative should be carried out.

The student can obtain much guidance from this document and can see clearly the amount of elastic–plastic fracture mechanics involved. The applications are complicated and the use of PD 6493 should be subject to expert advice.

City and Guilds of London Institute examination questions

Welding science, metallurgy and technology

Note: All dimensions are given in millimetres, unless otherwise stated.

1 A butt weld is to be made by the manual metal arc process between two 2 m by 1 m by 10 mm thick low-carbon steel plates along the long side.
   (*a*) Explain briefly why the cooling rate should be controlled.
   (*b*) State *three* factors which may influence the cooling rate of the weld.

2 What is meant by distortion of welded work? State *four* factors which may cause distortion during the welding of mild steel assemblies. Describe briefly one method used to control distortion when building up a short section of a 75 mm diameter steel shaft worn below the correct diameter.

3 Discuss briefly safety recommendations with regard to each of the following:
   (*a*) the type of current used in dangerous situations,
   (*b*) metal arc welding in confined spaces,
   (*c*) effects due to (1) arc radiations and (2) heat exhaustion,
   (*d*) earthing and conductivity of the welding return circuit.

4 Give *one* reason for the use of *each* of the following in welded work:
   (*a*) a chill,
   (*b*) a heat retaining material,
   (*c*) a fixture.

5 Make sectional sketches of the following weld joints and give their weld symbol in accordance with the appropriate BS 499:
   (*a*) close-square-tee fillet (weld both sides),
   (*b*) single bevel butt.

6 What are meant by the following terms:
  (*a*) conduction,
  (*b*) convection,
  (*c*) radiation.

Give *one* example of each welding practice.

7 Explain the procedure which must be carried out in order to make an effective macroscopic examination of a transverse section through a welded joint in low-carbon steel, naming *four* defects which may be revealed by this method of examination.

8 A dye penetrant method may be used for detecting defects in a welded joint.
  (*a*) Outline the principles of this method.
  (*b*) What type of defects may be revealed?

9 Explain briefly the meaning of *each* of the following electrical terms:
  (*a*) voltage,
  (*b*) current,
  (*c*) resistance.

10 State *two* advantages in *each* case of:
  (*a*) hot working,
  (*b*) cold working in a low-carbon steel.

11 (*a*) Describe briefly the effect of cold rolling on the grain structure of a metal.
  (*b*) Explain what takes place when a metal that has been cold rolled is heated to its recrystallization temperature.

12 Describe briefly the difference between the current pick-up systems for the generation of alternating current and direct current.

13 (*a*) Give *two* reasons why grain growth may take place in a metal.
  (*b*) What effect will enlarged grain structures have on the mechanical properties of a metal?

14 Explain briefly why oxygen and nitrogen should be excluded throughout the welding operation.

15 In relation to manual metal arc welding state *two* functions in *each* case of:
  (*a*) fluxes,
  (*b*) slags.

16 For each of the following cases state which kind of cracking is most likely to occur in a fusion welded joint:
  (*a*) a weld highly stressed during the early stages of solidification,
  (*b*) a weld in a hardenable steel made without pre-heat,
  (*c*) a weld in an unstabilized austenitic stainless steel.

17 In the welding of a solution-treatable type of aluminium alloy, describe any *two* weldability difficulties that you would expect to encounter.

18 (*a*) Name two practical difficulties likely to be encountered in inspecting a weld joint by radiographic means.
(*b*) Why are magnetic crack detection methods not used for examining welds in copper alloys?
(*c*) What crack detection method could be used for copper alloys?

19 (*a*) For a plain carbon steel containing 0.4%C list three typical metallurgical states which might exist in the material in the vicinity of a fusion weld.
(*b*) For each of the conditions under (*a*), outline the sequence of heating and cooling that would put the material in that particular condition.

20 State the purpose of a drooping characteristic for arc welding. Sketch the form of a drooping characteristic and indicate on it:
(*a*) the open circuit voltage,
(*b*) the average arc voltage,
(*c*) the average welding current.

21 On a labelled outline sketch:
(*a*) name the different types of structure that you would expect to find in the vicinity of a single-run-vee butt weld made in an initially *annealed* solution-heat-treatable alloy, and
(*b*) indicate the approximate areas in which you would expect to find each structure.

Note: you are expected only to name the type of structure, not to show any details.

22 (*a*) Why is it that residual stress tends to become less of a problem the faster you are able to complete an arc-welded joint?
(*b*) Give *one* reason why a particular material might be very liable to hot cracking.

23 State briefly any *two* problems likely to be met in trying to weld an alloy containing one relatively low-melting-temperature constituent and with a wide solidification range of temperature.
What is meant by the term 'low-alloy steel'?

24 (*a*) What is the most commonly used ferrous alloy?
(*b*) Name *two* different non-ferrous alloys used in welded fabrications.
(*c*) State *two* conditions essential for the formation of an equi-axial crystal structure, in an arc welded deposit in the as-welded condition.

25 (*a*) In *each* of the following cases state a possible cause of *one* type of cracking which may be produced in fusion welded joints made in:
(1) low-alloy hardenable steels,
(2) austenitic heat resisting steels.
(*b*) Outline why it is important to avoid sharp corners in fusion welded joints made in structural steel for service at low temperatures.

26 (*a*) What is meant by the critical cooling rate of a plain carbon steel?
(*b*) State *two* detrimental effects which may be produced during the making of a welded joint in 0.4% carbon steel if the critical cooling rate is exceeded.

27 (*a*) Describe the effects on the weldability of low-alloy steel of any *two* of the following elements:
(1) nickel,
(2) chromium,
(3) hydrogen.
(*b*) Explain how the difficulties which may arise from the presence of hydrogen may be overcome during the welding of low-alloy steels.

28 A low-carbon steel open-top tank 7 m in mean diameter by 5 m deep by 20 mm thick is to be fabricated by welding. Calculate the total mass of plate if the metal density is 7830 kg/m^3, taking π as 22/7.
Ten low-carbon steel plates each 3 m by 2 m by 20 mm thick are required to make an oil tank. Calculate the total mass of plate used if the metal density is 7830 kg/m^3.

29 Make a sectional sketch of *each* of the following types of welded joint, giving the appropriate weld symbol to show these joints in accordance with BS 499:
(*a*) single 'U.' butt,
(*b*) double-bevel butt.

30 Describe with the aid of sketches where appropriate, how defects may be detected by using each of the following methods of testing:
(*a*) X-ray,
(*b*) ultrasonic,
(*c*) dye penetrant.

31 Explain by means of a sketch what is meant by temperature gradient.

32 State two important functions of fluxes used during oxy-acetylene welding operations.

33 Name two main types of weld testing and give one example of each type.

34 Stainless steel filler rod used for oxy-acetylene welding usually contains an element known as a stabilizer. Name one such element and state its main purpose.

35 (*a*) What is meant by 'post-heating'?
(*b*) State two reasons why welded assemblies may be subjected to post-heating.

36 Increasing the carbon content of a plain steel influences certain physical properties. Using one word only in each case, state the effect of increase in carbon content on the following properties:
(*a*) tensile strength,
(*b*) elongation,
(*c*) hardness,
(*d*) melting points.

37 (*a*) Describe, in detail, the preparation and procedure for making a controlled root bend test from a 5 mm thick low-carbon steel test piece taken from a butt welded joint.
(*b*) State two desirable features such a bend test should reveal.

38 State briefly how any *four* of the following may arise in welding practice and explain how *each* may be counteracted:
(*a*) grain growth in a brass,
(*b*) over-ageing of precipitation hardenable aluminium alloys,
(*c*) residual stresses in low-carbon steel,
(*d*) interangular corrosion of austenitic stainless steel,
(*e*) cold cracking of low-alloy, high-tensile steel.

39 Outline *two* workshop methods of distinguishing a grey iron casting from a malleable iron casting.

40 Give two examples of difficulties which may be encountered in the welding of high thermal conductivity materials.

41 Describe with the aid of a simple sketch what is meant by a 'pearlitic structure'.

42 (*a*) What is meant by 'hot shortness'?
(*b*) Give two causes of this weakness.

43 Why is alternating current potentially more dangerous than direct current at the same nominal voltage.

44 (*a*) In what type of weld would you expect to find a columnar structure?
(*b*) With the aid of a sketch, show in which part of the weld you would find this structure.

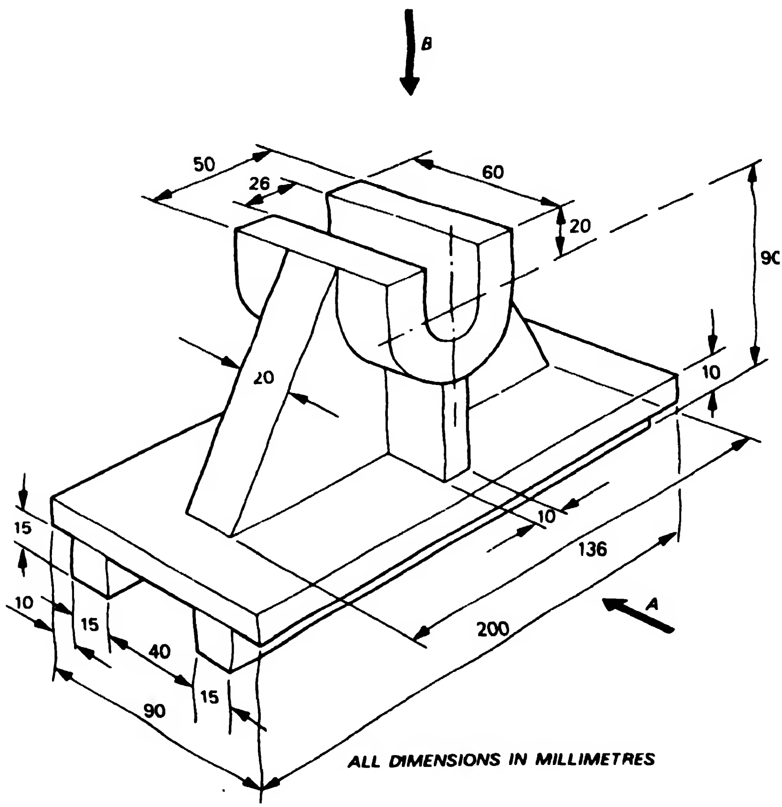
45 Explain how rapid cooling affects the microstructure of an 18% nickel-steel weld metal.

46 Explain the essential difference between macroscopic and microscopic examination.

47 The figure shows a pictorial view of a bracket to be produced by welding. Sketch, approximately half full size, an elevation in direction of arrow '*A*' and a plan view in direction of arrow '*B*'. Insert on the sketch the appropriate weld symbols according to BS 499 in order to indicate the welded joints necessary to fabricate the bracket.

48 (*a*) What is meant by a metallic solid solution?
(*b*) Give one example of a solid solution using an alloy which is normally welded.

Question 47



49 State the purpose of each of the following components of an arc welding plant:
- (*a*) rectifier,
- (*b*) transformer,
- (*c*) choke reactance.

50 Briefly explain the function of *each* of the following in manual metal arc welding:
- (*a*) a low-voltage safety device,
- (*b*) a rectifier.

51 List *six* methods of testing welded joints, indicating clearly whether the methods are destructive or non-destructive.

52 (*a*) Give *three* reasons why pre-heating is sometimes necessary when manual metal arc welding.
- (*b*) Briefly describe how pre-heating may be carried out by an electro-thermal method.

53 State *two* physical properties and *one* metallurgical problem that must be encountered when joining dissimilar materials by a fusion welding process.

54 In *each* case, list *six* factors that would require attention while carrying out visual inspection of metal arc welded work:
- (*a*) prior to welding,
- (*b*) during welding,
- (*c*) after welding.

55 Describe the effects on the weldability of steel of *each* of the following elements and state in *each* case *one* method of overcoming difficulties that may arise:
- (*a*) carbon,
- (*b*) hydrogen,
- (*c*) silicon,
- (*d*) chromium.

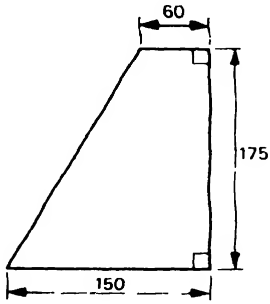
56 (*a*) Explain why a destructive macrostructural examination of the cross-section of a weld is often required.
- (*b*) Why is the welding craftsman not normally expected to make a macrostructural examination of a weld?

57 (*a*) Why may magnetic particle inspection only be used for crack detection in carbon steel and some alloy steels, whereas dye penetrant methods can be applied to all metals?
- (*b*) Name *four* of the most possible causes of cracking in welds made by metal arc gas-shielded welding.

58 The figure shows the dimensions of a gusset plate. Calculate the area of plate required to make 50, assuming no wastage.

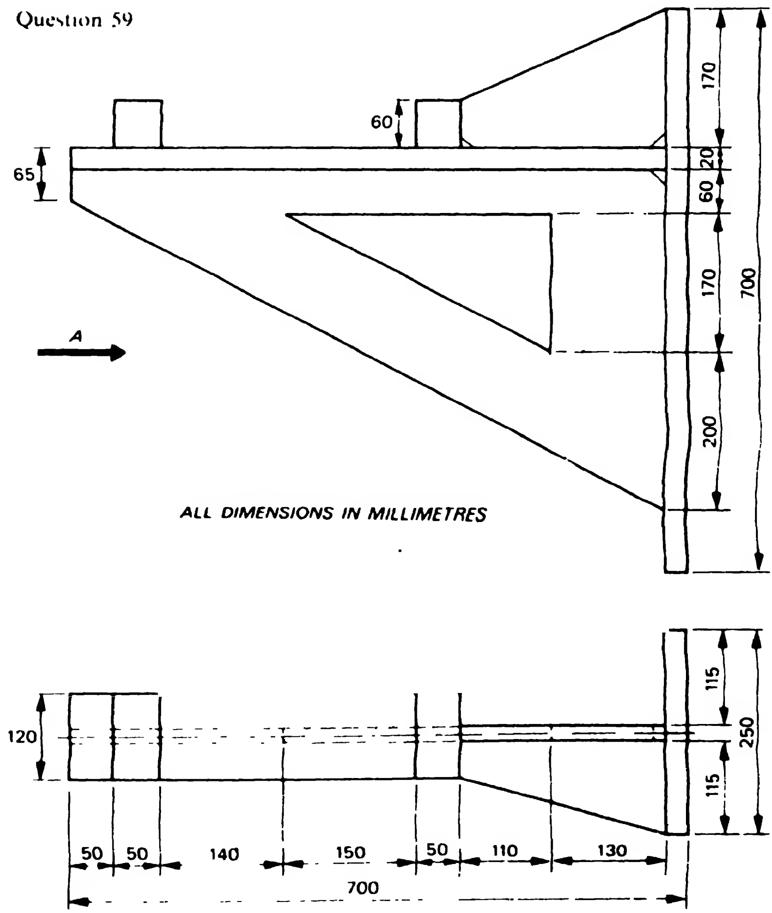
59 Draw and fully dimension, in the direction of arrow *A*, an end elevation of the welded bracket shown in the figure. Insert the appropriate weld symbols according to BS 499 on the welded joints used.

Question 58



ALL DIMENSIONS IN MILLIMETRES

Question 59



60 Give three reasons for the use of pre-heat in welding applications. Explain one method of pre-heat.

61 (*a*) Give two causes of hot cracking in carbon-steel fusion welds.
(*b*) Name one impurity that may cause hot cracking in welded steel joints.
(*c*) State one way in which hot cracking can be minimized by welding procedure.

62 (*a*) Explain briefly what is meant by solution treatment.
(*b*) Give one example of an alloy that may be solution treated.
(*c*) What effect will fusion welding have on the mechanical properties of a solution-treated alloy?

63 State *two* conditions essential for the formation of an equi-axial crystal structure, in an arc welded deposit in the as-welded condition.

64 If treated alloy plates, in the fully solution-treated and aged condition, are joined by fusion welding state whether:
(*a*) the as-welded deposit will be harder or softer than the parent plate.
(*b*) the heat-affected zone will be harder or softer than the parent plate.

65 (*a*) Briefly describe the mode of solidification leading to columnar grain structure in an autogenous welded joint made by tungsten-arc welding.
(*b*) Give *one* example of a type of material in which a band of refined grain structure may be expected nearest to the weld boundary in the heat-affected zone of a fusion welded joint.

66 (*a*) Give *two* examples of when pre-heating is essential in the fusion welding of carbon steels
(*b*) Explain why the presence of moisture in any form should be avoided when gas-shielded arc welding low-alloy steels.

67 (*a*) What is meant by the critical cooling rate of a plain carbon steel?
(*b*) State *two* detrimental effects which may be produced during the making of a welded joint in 0.4% carbon steel if the critical cooling rate is exceeded.

68 (*a*) Give *one* example of *either* dilution *or* pick-up effects arising in gas-shielded arc welding practice.
(*b*) State the shielding gas or gas mixture which is best suited to obtain the required modes of metal transfer for the effective

metal arc gas-shielded welding of *each* of the following:
(1) low-carbon steel by dip transfer,
(2) austenitic stainless steel by controlled spray (pulse) transfer.

69 (*a*) Explain, with the aid of a sketch, how the level of dilution of a butt-welded joint may be determined.
(*b*) Show by means of a labelled sketch *one* type of edge preparation used to control pick-up effects when making a butt-welded joint in clad steel.

70 State what is meant by a metallic alloy and name one non-ferrous alloy used in welded fabrications.

71 Give *three* reasons why hot cracking may be a problem when manual metal-arc welding austenitic stainless steel.

72 (*a*) Explain the difference between stress relieving and annealing in the heat treatment of steels.
(*b*) State whether the heat-affected zone will be harder or softer than the parent plate in a fusion welded joint made in fully solution-treated and aged alloy plates.

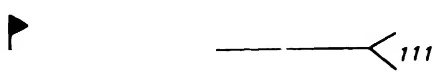
73 (*a*) The figure shows the arrow line and reference line according to BS 499 Part 2, 1980. State for both the symbols shown what information they convey.
(*b*) State what is meant by the critical cooling rate of a plain carbon steel.
(*c*) Give *two* examples of when pre-heating is essential in the fusion welding of carbon steels.
(*d*) List *four* factors that should be considered when determining the pre-heating temperature to be used for welding a steel fabrication.

74 (*a*) Explain the difference between the heat treatment processes 'annealing' and 'normalizing'.
(*b*) State *three* advantages obtained by normalizing alloy steel welded joints.

75 The equivalent carbon content of an alloy steel can be found from the formula:

$$\text{Carbon equivalent} = \%C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

Question 73



The composition of an alloy steel is as shown in the table:

Carbon	Phosphorus	Sulphur	Vanadium	Chromium	Manganese	Silicon
0.22%	0.05%	0.05%	0.10%	0.10%	1.50%	0.50%

(*a*) Using the formula given, calculate the carbon equivalent.
(*b*) State *two* precautions to be taken when welding this type of steel.

76 State what is meant by a metallic alloy and name one non-ferrous alloy used in welded fabrications.

77 If the parent metal composition of a welded joint in plain carbon steel is 0.22% carbon, the all-weld metal deposit composition is 0.11% carbon and the cross-sectional area of the weld metal zone is 10 times the size of the cross-sectional area of the fusion zone, estimate the approximate average carbon content of the weld deposit resulting from dilution.

78 (*a*) Give one reason why the hard brittle form of structure (martensite) is most likely to form close beside the fusion boundary in the heat-affected zone of a welded joint in a hardenable steel.
(*b*) Name the kind of structure to be found *just outside* a martensitic zone in the heat-affected zone of a welded joint in a hardenable steel (*Note*. If you do not know the technical name of the structure a simple word description will do.)

79 (*a*) What is the purpose of a rectifier when used for welding from a.c. power supply?
(*b*) On a simple labelled graph shown clearly the typical form of current flow likely to be obtained from a welding rectifier.

80 A metallic alloy may have a 'narrow' or a 'wide' solidification range.
(*a*) State which type of solidification mode will give most difficulty in fusion welding.
(*b*) Give *one* reason to justify your answer.

81 (*a*) What is the most commonly used ferrous alloy?
(*b*) Name *two* different non-ferrous alloys used in welded fabrications.

82 (*a*) If your welding generator caught fire and you could not switch off the supply current, what type of fire extinguisher would you use?
(*b*) Is there any type of extinguisher that you should not use?
(*c*) Why should you not use the type of extinguisher in (*b*).

83 Explain why a welding generator neither blows its fuse nor burns out when a short-circuit occurs at the welding electrode.

84 In the welding of a solution-treatable type of aluminium alloy, describe any *two* weldability difficulties that you would expect to encounter.

85 If you are *tungsten arc* gas-shielded welding a butt joint in 0.4% C steel plate 12 mm thick with 0.1% C steel filler wire, estimate the approximate average carbon content of the deposit.

86 If you are *metal arc* gas-shielded welding a butt joint in 0.4% C steel plate 12 mm thick with 0.1% C steel filler wire, estimate the approximate average carbon content.

87 (*a*) With what type of material would you expect to find equi-axial solidification occurring in a fusion welded deposit?
(*b*) Why is a columnar growth almost invariably found in the structure of a progressive fusion weld in the as-welded state?
(*c*) State the type of grain structure which may be found in the heat-affected zone of a single-run weld made in normalized low-carbon steel.

88 In the cross-sectional shape of a fusion welded joint, sharp corners should be avoided.
(*a*) Give the most important reason for this precaution.
(*b*) State why this precaution is particularly important when welding structural steel for service in a cold atmosphere.

89 When would it not be safe to connect two welding generators in parallel to give increased power to a single arc?

90 (*a*) Why is it that residual stress tends to become less of a problem the faster you are able to complete an arc-welded joint?
(*b*) Give *one* reason why a particular material might be very liable to hot intergranular cracking during fusion welding.

91 (*a*) What is dilution in fusion welding?
(*b*) What is pick-up in fusion welding?
(*c*) Can the atmosphere surrounding an arc affect any pick-up that normally tends to occur?

92 Draw a simple outline sketch of the cross-section of a two-run double V butt weld in a hardenable steel made without pre-heating and show (*a*) *three* different types of structure that might be found in the heat-affected zones, and (*b*) the most likely location(s) of each of the types you give. You are not expected to

give details of the structure; a simple general word description will be sufficient if you do not know the technical name of a particular structure.

93 State briefly any *two* problems likely to be met in trying to weld an alloy containing one relatively low-melting-temperature constituent and with a wide solidification range of temperature. What is meant by the term 'low-alloy steel'?

94 State briefly how any *four* of the following may arise in welding practice and explain how *each* may be counteracted:
(*a*) grain growth in brass,
(*b*) over-ageing of precipitation hardenable aluminium alloys,
(*c*) residual stresses in low-carbon steel,
(*d*) intergranular corrosion of austenitic stainless steel,
(*e*) cold cracking of low-alloy, high-tensile steel.

95 State three ways in which weather conditions may adversely affect welding operations.

96 (*a*) In what form would you expect the carbon to be present in (1) white cast iron, (2) grey cast iron.
(*b*) Which of these types of iron would most likely be formed in the heat-affected zone if the cooling rate after welding was too fast.

97 (*a*) Give any three advantages obtained when using rectifier welding equipment.
(*b*) Explain what is meant by the terms 'arc voltage' and 'open circuit voltage'.
(*c*) Give three probable causes of poor-quality resistance spot welds.

98 (*a*) Name *three* obnoxious fumes or poisonous gases which may be formed during metal arc welding operations.
(*b*) Give *two* safety precautions to be taken in order to avoid personal injury from these fumes or gases.

99 List *six* methods of testing welded joints, indicating clearly whether the methods are destructive or non-destructive.

100 (*a*) Explain what is meant by dilution in weld deposits.
(*b*) List *three* factors which may influence the amount of dilution produced in a weld deposit.

101 (*a*) Briefly explain why notch effects must be avoided in stressed welded structures.
(*b*) Sketch *two* defects and *two* undesirable weld contours, *each* of which could create notch effects.

102 (*a*) For a plain carbon steel containing 0.4% C list three typical metallurgical states which might exist in the material in the vicinity of a fusion weld.

(*b*) For each of the conditions under (*a*), outline the sequence of heating and cooling that would put the material in that particular condition.

103 For each of the following cases state which kind of cracking is most likely to occur in a fusion welded joint:

(*a*) a weld highly stressed during the early stages of solidification,

(*b*) a weld in a hardenable steel made without pre-heat,

(*c*) a weld in an unstabilized austenitic stainless steel.

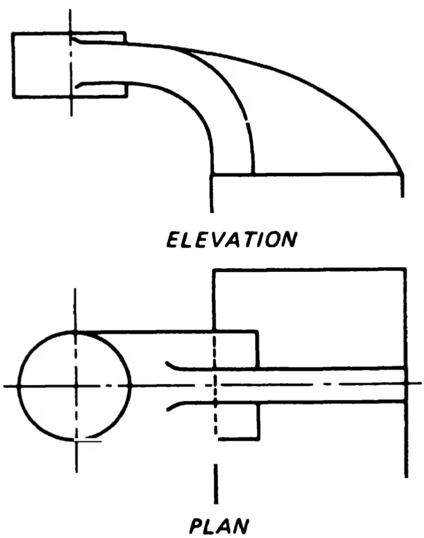
104 (*a*) Name two practical difficulties likely to be encountered in inspecting a weld joint by radiographic means.

(*b*) Why are magnetic crack detection methods not used for examining welds in copper alloys?

(*c*) What crack detection method could be used for copper alloys?

105 Make a pictorial sketch of the bracket shown in the figure.

Question 105



106 With the aid of sketches, explain what is meant by *each* of the following weld sequences:
(*a*) skip,
(*b*) block,
(*c*) back step.

107 A butt welded specimen is to be tested for impact value.
(*a*) Name a test that could be used.
(*b*) State the mechanical property that would be measured.
(*c*) State the effect that low temperature has on the impact resistance of carbon steels.

108 Explain the differences between brittle fracture and hot cracking which may occur in welded fabrications. In *each* case give *one* reason why these types of failure may occur.

109 The figure shows a steel plate with *three* slots cut in it. Calculate the surface area remaining.
Take π as $\frac{22}{7}$.

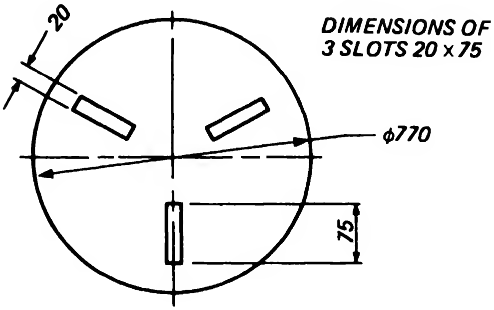
110 Martensite may be formed when arc welding steel.
(*a*) State *two* conditions which may cause it to be formed.
(*b*) State *three* methods which could be used to prevent its formation.

111 Steels may be classified according to their range of tensile strengths expressed in newtons per square millimetre.
(*a*) Explain what is meant by the term newton.
(*b*) Name and explain the test shown in the figure.

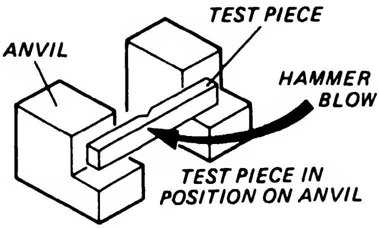
112 In the table below each term used in column *A* is directly related to *one* of the terms used in column *B*. Pair each of the terms listed in column *A* with the appropriate term in column *B*.

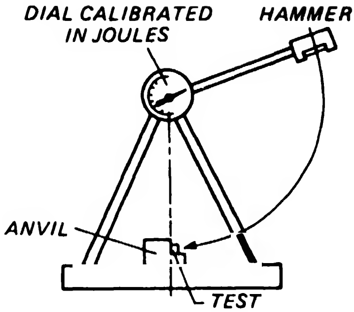
Column *A*	Column *B*
Hot cracking	High arc voltage
Health hazard	Iron sulphide
Cellulose covering	Phosgene gas
Rutile covering	High carbon equivalent
Cold cracking	Titanium dioxide

Question 109



Question 111





Part 2

The practice of welding

8

*Manual metal arc welding**

The electric arc

An electric arc is formed when an electric current passes between two electrodes separated by a short distance from each other. In arc welding (we will first consider direct-current welding) one electrode is the welding rod or wire, while the other is the metal to be welded (we will call this the plate). The electrode and plate are connected to the supply, one to the + ve pole and one to the − ve pole, and we will discuss later the difference which occurs when the electrode is connected to −ve or +ve pole. The arc is started by momentarily touching the electrode on to the plate and then withdrawing it to about 3 to 4 mm from the plate. When the electrode touches the plate, a current flows, and as it is withdrawn from the plate the current continues to flow in the form of a 'spark' across the very small gap first formed. This causes the air gap to become ionized or made conducting, and as a result the current is able to flow across the gap, even when it is quite wide, in the form of an arc. The electrode must always be touched on to the plate before the arc can be started, since the smallest air gap will not conduct a current (at the voltages used in welding) unless the air gap is first ionized or made conducting.

The arc is generated by electrons (small negatively charged particles) flowing from the −ve to the +ve pole and the electrical energy is changed in the arc into heat and light. Approximately two-thirds of the heat is developed near the +ve pole, which burns into the form of a crater, the temperature near the crater being about 6000–7000°C, while the remaining third is developed near to the −ve pole. As a result an electrode connected to the +pole will burn away 50% faster than if connected to the −ve pole. For this reason it is usual to connect medium-coated electrodes and bare

* Abbreviated MMA. American designation: shielded metal arc welding (SMAW).

rods to the −ve pole, so that they will not burn away too quickly. Heavily coated rods are connected to the +ve pole because, due to the extra heat required to melt the heavy coating, they burn more slowly than the other types of rods when carrying the same current. The thicker the electrode used, the more heat is required to melt it, and thus the more current is required. The welding current may vary from 20 to 600 A in manual metal arc welding.

When alternating current is used, heat is developed equally at plate and rod, since the electrode and plate are changing polarity at the frequency of the supply.

If a bare wire is used as the electrode it is found that the arc is difficult to control, the arc stream wandering hither and thither over the molten pool. The globules are being exposed to the atmosphere in their travel from the rod to the pool and absorption of oxygen and nitrogen takes place even when a short arc is held. The result is that the weld tends to be porous and brittle.

The arc can be rendered easy to control and the absorption of atmospheric gases reduced to a minimum by 'shielding' the arc. This is done by covering the electrode with one of the various types of covering previously discussed, and as a result gases such as hydrogen and carbon dioxide are released from the covering as it melts and form an envelope around the arc and molten pool, excluding the atmosphere with its harmful effects on the weld metal. Under the heat of the arc chemical compounds in the electrode covering also react to form a slag which is liquid and lighter than the molten metal. It rises to the surface, cools and solidifies, forming a protective covering over the hot metal while cooling and protecting it from atmospheric effects, and also slows down the cooling rate of the weld. Some slags are self-removing while others have to be lightly chipped **(Fig. 8.1)**.

The electrode covering usually melts at a higher temperature than the wire core so that it extends a little beyond the core, concentrating and directing the arc stream, making the arc stable and easier to control. The difference in controllability when using lightly covered electrodes and various medium- and heavily covered electrodes will be quickly noticed by the operator at a very early stage in practical manual metal arc welding.

With bare wire electrodes much metal is lost by volatilization, that is turning into a vapour. The use of covered electrodes reduces this loss.

An arc cannot be maintained with a voltage lower than about 14 V and is not very satisfactory above 45 V. With d.c. sources the voltage can be varied by a switch or regulator, but with a.c. supply by transformer the open circuit voltage (OCV) choice is less, being 80 or 100 V on larger units, down to 50 V on small units.

The greater the volts drop across the arc the greater the energy liberated in heat for a given current.

Arc energy is usually expressed in kilojoules per millimetre length of the weld (kJ/mm) and

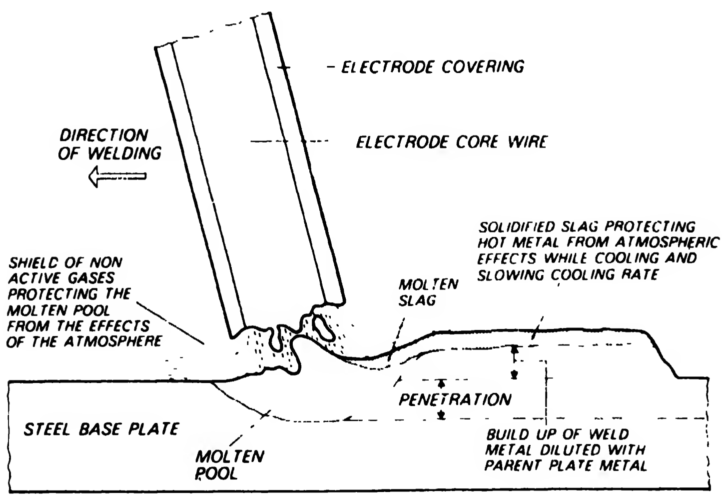
$$\text{Arc energy (kJ/mm)} = \frac{\text{arc voltage} \times \text{welding current}}{\text{welding speed (mm/s)} \times 1000}.$$

The volts drop can be varied by altering the type of gas shield liberated by the electrode covering, hydrogen giving a higher volts drop than carbon dioxide for example. As the length of the arc increases so does the voltage drop, but since there is an increased resistance in this long arc the current is decreased. Long arcs are difficult to control and maintain and they lower the efficiency of the gas shield because of the greater length. As a result, absorption of oxygen and nitrogen from the atmosphere can take place, resulting in poor mechanical properties of the weld. It is essential that the welder should keep as short an arc as possible to ensure sound welds.

Transference of metal across the arc gap

When an arc is struck between the electrode and plate, the heat generated forms a molten pool in the plate and the electrode begins to melt away, the metal being transferred from the electrode to the plate. The transference takes place whether the electrode is positive or negative and also when it has a changing polarity, as when used on a.c. Similarly it is

Fig. 8.1. The shielded arc. Manual arc weld on steel base plate with a covered electrode



transferred upwards against the action of gravity, as when making an overhead weld. Surface tension plays an important part in overhead welding and a very short arc must be held to weld in the overhead position successfully.

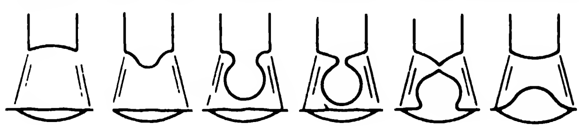
The forces which cause the transfer appear to be due to: (1) its own weight, (2) the electro-magnetic (Lorentz) forces, (3) gas entrainment, (4) magneto-dynamic forces producing movement and (5) surface tension. The globule is finally necked off by the magnetic pinch effect.

If the arc is observed very closely, or better still if photographs are taken of it with a slow-motion cine-camera, it can be seen that the metal is transferred from the electrode to the plate in the form of drops or globules, and these globules vary in size according to the current and type of electrode covering. Larger globules are transferred at longer intervals than smaller globules and the globules form, elongate with a neck connecting them to the electrode, the neck gets reduced in size until it breaks, and the drop is projected into the molten pool, which is agitated by the arc stream, and this helps to ensure a sound bond between weld and parent metal. Drops of water falling from a tap give an excellent idea of the method of transference (see Fig. 8.2). Other methods of transfer known as dip (short circuiting arc) and spray (free flight transfer) are discussed in the section on MIG welding process.

Arc blow

We have seen that whenever a current flows in a conductor a magnetic field is formed around the conductor. Since the arc stream is also a flow of current, it would be expected that a magnetic field would exist around it, and that this is so can be shown by bringing a magnet near the arc. It is seen that the arc is blown to one side by the magnet, due to the interaction of its field with that of the magnet (just as two wires carrying a current will attract each other if the current flows in the same direction in each, or repel if the currents are in opposite directions), and the arc may even be extinguished if the field due to the magnet is strong enough. When welding, particularly with d.c., it is sometimes found that the arc tends to wander and becomes rather uncontrollable, as though it was being blown to and fro. This is known as arc blow and is experienced most when using

Fig. 8.2. Detachment of molten globule in the metal arc process



currents above 200 or below 40 A, though it may be quite troublesome, especially when welding in corners, in between this range. It is due to the interaction of the magnetic field of the arc stream with the magnetic fields set up by the currents in the metal of the work or supply cables. The best methods of correction are:

(1) Weld away from the earth connexion.
(2) Change the position of the earth wire on the work.
(3) Wrap the welding cable a few turns around the work, if possible, on such work as girders, etc.
(4) Change the position of the work on the table if working on a bench.

In most cases the blow can be corrected by experimenting on the above lines, but occasionally it can be very troublesome and difficult to eliminate. Alternating-current welding has the advantage that since the magnetic field due to the arc stream is constantly alternating in direction at the frequency of the supply, there is much less trouble with arc blow, and consequently this is very advantageous when heavy currents are being used. Arc blow can be troublesome in the TIG and MIG processes, particularly when welding with d.c.

Spatter

At the conclusion of a weld small particles or globules of metal may sometimes be observed scattered around the vicinity of the weld along its length. This is known as 'spatter' and may occur through:

(1) Arc blow making the arc uncontrollable.
(2) The use of too long an arc or too high an arc voltage.
(3) The use of an excessive current.

The latter is the most frequent cause.

Spatter may also be caused by bubbles of gas becoming entrapped in the molten globules of metal, expanding with great violence and projecting the small drops of metal outside the arc stream, or by the magnetic pinch effect, by the magnetic fields set up, and thus the globules of metal getting projected outside the arc stream.

Spatter can be reduced by controlling the arc correctly, by varying current and voltage, and by preventing arc blow in the manner previously explained. Spatter release sprays ensure easy removal.

Eccentricity of the core wire in an MMA welding electrode

If the core wire of a flux-coated electrode is displaced excessively from the centre of the flux coating because of errors in manufacture, the arc may not function satisfactorily. The arc tends to be directed towards one

side as if influenced by 'arc blow' and accurate placing of the deposited metal is prevented (Fig. 8.3*a*). A workshop test to establish whether the core wire is displaced outside the manufacturer's tolerance is to clean off the flux covering on one side at varying points down the length of the electrode and measure the distance L (Fig. 8.3*b*). The difference between the maximum and minimum reading is an approximate indication of the eccentricity.

Electrode efficiency. The efficiency of an electrode is the mass of metal actually deposited compared with the mass of that portion of the electrode consumed. It can be expressed as a percentage thus:

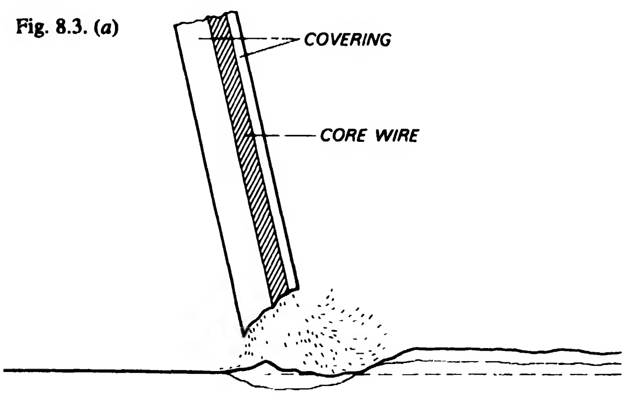
$$\text{efficiency \%} = \frac{\text{mass of metal deposited}}{\text{mass of metal of the electrode consumed}} \times 100.$$

With ordinary electrodes the efficiency varies from 75% to 95% but with electrodes containing metallic components in the covering the efficiency can approach 200% (e.g. electrodes containing iron powder).

In the electrode classification (British), efficiencies of 110% and above are indicated by a three-digit figure in the additional section of the electrode coding, giving the efficiency rounded to the nearest 10, with values ending in 5 being rounded up (BS 639 (1986)).

The efficiency of a particular type of electrode can be obtained by taking a clean steel plate (up to 0.25% carbon) and weighing it, say m_1 g. Electrodes of a mass of 20% m_1 g are completely stripped of their covering and weighed, say m_3 g (weighing tolerances are ± 1 g). A similar number of electrodes to those stripped are then deposited on the plate with an interpass temperature not greater than 100 °C, until each stub length is 50 mm. Slag and spatter are cleaned from each run when deposited and the plate completely cleaned after the final deposit. It is then weighed, say

Fig. 8.3. (*a*)



m_2 g, so that the increase in mass of the plate (i.e. the mass of the deposited metal) is $(m_2 - m_1)$ g.

The stubs have any covering remaining on them removed and are weighed, say m_4 g; thus the mass of metal to be deposited is $(m_3 - m_4)$ g.

The nominal (N) electrode efficiency R_N % is given by:

$$R_N = \frac{(m_2 - m_1)}{(m_3 - m_4)} \times 100$$

$$\text{or} \quad \frac{\text{mass of deposited metal}}{\text{mass of core wire before depositing} - \text{mass of stub wire}}$$

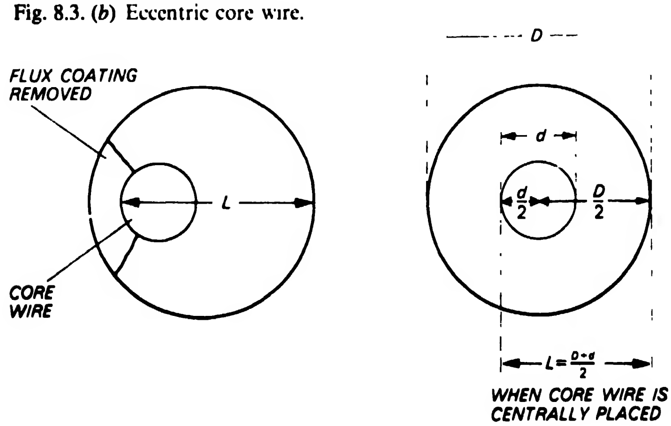
Electrodes should be tested according to the maker's instructions regarding d.c. or a.c. and polarity. Full details for obtaining the nominal electrode efficiency are given in BS 639 (1986), appendix C.

High efficiency electrodes

The deposition rate of a given electrode is dependent upon the welding current used, and for maximum deposition rate, maximum current should be used. This maximum current depends upon the diameter of the core wire, and for any given diameter of wire there is a maximum current beyond which increasing current will eventually get the wire red hot and cause overheating and hence deterioration of the covering.

To enable higher currents to be used an electrode of larger diameter core wire must be used, but if metallic components such as iron powder are added to the covering of the electrode, this covering becomes conducting, and a higher welding current can now be used on an electrode of given core wire diameter. The deposition rate is now increased and in addition the iron powder content is added to the weld metal, giving greater

Fig. 8.3. (*b*) Eccentric core wire.



efficiency, that is enabling more than the core wire weight of metal to be deposited because of the extra iron powder. Efficiencies of up to 200 % are possible, this meaning that twice the core wire weight of weld metal is being deposited. These electrodes can have coverings of rutile or basic type or a mixture of these. The iron powder ionizes easily, giving a smoother arc with little spatter, and the cup which forms as the core wire burns somewhat more quickly than the covering gives the arc directional properties and reduces loss due to metal volatilization. See also Electrode efficiency (metal recovery and deposition coefficient).

Hydrogen-controlled electrodes (basic covered)*

If oxygen is present with molten iron or steel a chemical reaction occurs and the iron combines chemically with the oxygen to form a chemical compound, iron oxide. Similarly with nitrogen, iron nitride being formed if the temperature is high enough as in metal arc welding. When hydrogen is present however there is no chemical reaction and the hydrogen simply goes into solution in the steel, its presence being described as x millilitres of hydrogen in y grams of weld metal.

This hydrogen can diffuse out of the iron lattice when in the solid state resulting in a lowering of the mechanical properties of the weld and increasing the tendency to cracking. By the use of basic hydrogen-controlled electrodes, and by keeping the electrodes very dry, the absorption of hydrogen by the weld metal is reduced to a minimum and welds can be produced that have great resistance to cracking even under conditions of very severe restraint.

The coverings of these electrodes are of calcium or other basic carbonates and fluorspar bonded with sodium or potassium silicate. When the basic carbonate is heated carbon dioxide is given off and provides the shield of protective gas thus:

calcium carbonate (limestone) heated → calcium oxide (quicklime) + carbon dioxide

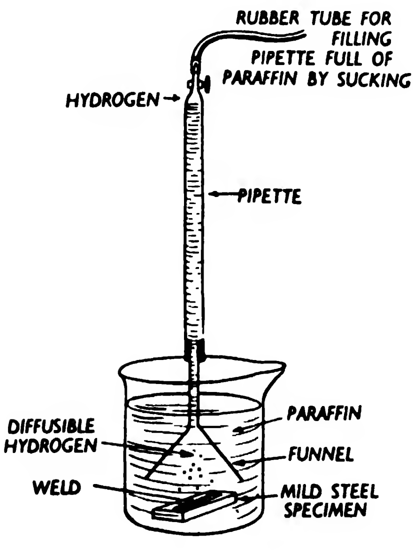
There is no hydrogen in the chemicals of the covering, so that if they are kept absolutely dry, the deposited weld metal will have a low hydrogen content. Electrodes which will give deposited metal having a maximum of 15 millilitres of hydrogen per 100 grams of deposited metal (15 ml/100 g) are indicated by the letter H in BS 639 (1986) classification. The absence of diffusible hydrogen enables free cutting steels to be welded with absence of porosity and cracking and the electrodes are particularly suitable for welding in all conditions of very severe restraint. They can be used on a.c. or d.c. supply according to the makers' instructions and are available also in

* Typical AWS classification of these electrodes may be E 7015 or E 7018, for example

iron powder form and for welding in all positions. Low and medium alloy steels which normally would require considerable pre-heat if welded with rutile-coated electrodes can be welded with very much less pre-heating, the welds resisting cracking under severe restraint conditions and also being very suitable for welding in sub-zero temperature conditions. By correct storage and drying of these electrodes the hydrogen content can be reduced to 5 ml/100 g of weld metal for special applications. Details of these drying methods are given in the section on storage and drying of electrodes (q.v.).

Experiment to illustrate the diffusible hydrogen content in weld metal. Make a run of weld metal about 80 mm long with the metal arc on a small square of steel plate using an ordinary steel welding rod with a cellulose, rutile or iron oxide coating. Deslag, cool out quickly and dry off with a cloth and place the steel plate in a beaker or glass jar of paraffin. It will be noted that minute bubbles of gas stream out of the weld metal and continue to do so even after some considerable time. If this gas is collected as shown in Fig. 8.4 it is found to be hydrogen which has come from the flux covering and the moisture it contains. A steel weld may contain hydrogen dissolved in the weld metal and also in the molecular form in any small voids which may be present. Hydrogen in steel produces embrittlement and a reduction in fatigue strength. If a run of one of these hydrogen-controlled electrodes is made on a test plate and the previous experiment repeated it will be noted that no hydrogen diffuses out of the weld.

Fig. 8.4. Collecting diffusible hydrogen from a mild steel weld.



BS 6693, Pt 1 (3-day collection) and Pt 2 (collection continued until there is no further increase of hydrogen) give methods of determining the quantity of diffusible hydrogen present in a specimen, together with drawings of apparatus for collecting this hydrogen.

Deep penetration electrodes

A deep penetration electrode is defined in BS 499, Part 1 (*Welding terms and symbols*) as 'A covered electrode in which the covering aids the production of a penetrating arc to give a deeper than normal fusion in the root of a joint'. For butt joints with a gap not exceeding 0.25 mm the penetration should be not less than half the plate thickness, the plate being twice the electrode core thickness. For fillet welds the gap at the joint should not exceed 0.25 mm and penetration beyond the root should be 4 mm minimum when using a 4 mm diameter electrode.

Welding position

Weld slope is the angle between line of the root of the weld and the horizontal (Fig. 8.5).

Weld rotation. Draw a line from the foot of the weld at right angles to the line welding to bisect the weld profile. The angle that this line makes with the vertical is the angle of weld rotation.

The table indicates the five welding positions used for electrode classification Any intermediate position not specified may be referred to as 'inclined'. (See also Figs. 8.6, 8.7, 8.8.)

Position	Slope	Rotation	Symbol	Fig.
Flat	0 5	0- 10	F	1.5
Horizontal- vertical	0 -5	30 -90	H	1.6
Vertical - up	80 90	0 180	V	1.7a
Vertical down	80 90	0-180	D	1.7b
Overhead	0 15	115 180	O	1.8

Storage of electrodes

The flux coverings on modern electrodes are somewhat porous and absorb moisture to a certain extent. The moisture content (or humidity) of the atmosphere is continually varying and hence the moisture content of the covering will be varying. Moisture could be excluded by providing a non-porous covering, but any moisture entrapped would be liable to cause

rupture of the coating when the moisture was turned to steam by the heating effect of the passage of the current through the electrode. Cellulosic electrodes absorb quite an appreciable amount of moisture, and it does not affect their properties since they function quite well with a moisture content. They should not be over-dried or the organic compounds of which

Fig. 8.5. Flat position

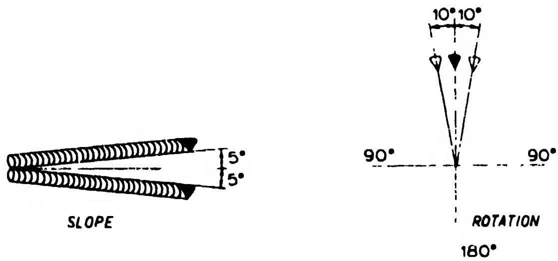


Fig. 8.6. Horizontal vertical position

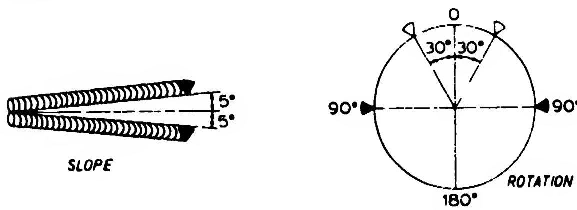


Fig. 8.7. (*a*) Vertical- up position. (*b*) Vertical-down position.

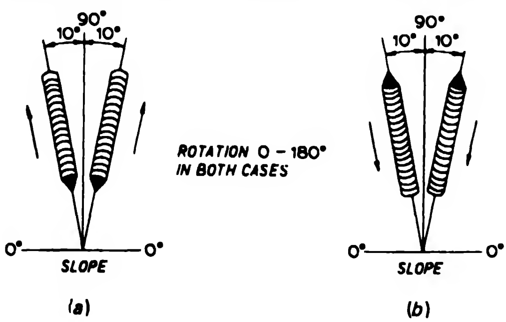
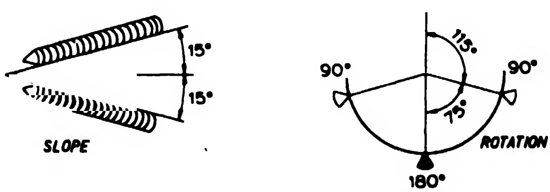


Fig. 8.8. Overhead position.



they are composed tend to char, affecting the voltage and arc properties. The extruded electrodes with rutile, iron oxide and silicate coatings do not pick up so much moisture from the atmosphere and function quite well with a small absorbed content. If they get damp they can be satisfactorily dried out, but it should be noted that if they get excessively wet, rusting of the core wire may occur and the coating may break away. In this case the electrodes should be discarded.

Storage temperatures should be about 12°C above that of external air temperature with 0–60% humidity. Cellulose covered electrodes are not so critical: but they should be protected against condensation and stored in a humidity of 0–90%.

Drying of electrodes. The best drying conditions are when the electrodes are removed from their package and well spaced out in a drying oven which has a good circulation of air. Longer drying times are required if the electrodes are not spaced out. The following table gives an indication of temperatures and times required, but see also the special conditions for drying basic electrodes (Fig. 8.9).

Drying of electrodes: approximate times and temperatures with electrodes spaced apart. Times will vary with air circulation, electrode spacing and oven loading

Electrode type	Diameter mm	Temperature C	Time in mins air circulation good	poor
Rutile mild steel	1.6–2.5	110	10–30	20–30
	3.2–5.0	110	20–45	30–60
	6.0–10.0	110	30–60	45–120
Cellulose	2.5–6.0	110	10–15	15–20

Hydrogen-controlled (basic) electrodes

The coatings of these electrodes contain no hydrogen-forming compounds, but if moisture is absorbed by the coating it becomes a source of hydrogen and cannot be tolerated. They must therefore be stored in a dry, heated and well-ventilated store on racks above floor level and unused electrodes should be returned to the store rather than left in the colder and moister conditions of the workshop where they could absorb moisture. A temperature of about 12°C above that of the external air temperature is suitable. Before use they should be removed from their package and spread

out in the drying oven, the drying time and temperature depending upon the permissible volume of hydrogen in the weld deposit. Suggested figures are given in the following table.

Hydrogen content in millilitres of hydrogen per 100 grams of weld metal	Temperature °C	Time minutes	Use
10–15 ml H_2/100 g	150	60	To give resistance to HAZ cracking in thick sections of mild steel, high restraint
5–10 ml H_2/100 g	200	60	High quality welds in pressure vessel and structural applications.
below 5 ml H_2/100 g	450	60	Thick sections to avoid lamellar tearing and critical applications.

In order to obtain high radiographic standards of deposited weld metal the drying periods given above may be extended. The following periods are given as an indication of prolonged drying times such that the electrode coating will not suffer a decrease in coating strength.

Drying temperature	Maximum time
150°C	72 hours
250°C	12 hours
450°C	2 hours

The makers' instructions for drying should be strictly adhered to.

Fig. 8.9.

Many electrodes if stored in damp situations get a white fur on their coverings. This is sodium carbonate produced by the action of the carbon dioxide (carbonic acid) of the atmosphere on the sodium silicate of the binder in the flux covering. The fur appears to have little detrimental effect on the weld but shows that the electrodes are being stored in too damp a situation.

Electrode classification (British)

Abridged classification for covered carbon and carbon–manganese steel electrodes for manual metal arc welding. BS 639 (1986)

Note: This classification is for deposited weld metal having a tensile strength not greater than 650 N/mm². Students should study the whole text of BS 639 (1986), which gives full details of the classification together with the tests involved. Weld metals with tensile strength greater than 650 N/mm² are dealt with in BS 2493 and BS 2926.

The classification is denoted by a code consisting of two parts: (*a*) a general code, followed by (*b*) an additional code in parentheses, for example E 43 2 2 RR (2 1).

(***a***) ***General code*** (strength, toughness and covering (STC) code). There are five elements in the general code (in the order given)

(1) the letter E indicating a covered electrode for manual metal arc welding
(2) two digits indicating the strength (tensile, yield and elongation properties of the weld metal) (see Table 1)
(3) one digit indicating the temperature for a minimum average impact value of 28 J (see Table 2)
(4) one digit indicating the temperature for a minimum average impact value of 47 J (see Table 3)
(5) either one or two letters indicating the type of covering, namely: B – basic; BB – basic, high efficiency; C – cellulosic; R – rutile; RR – rutile heavy coated; S – other types.

(***b***) ***Additional code.*** This has four elements, of which (1) and (4) are included only if appropriate.

(1) where appropriate, three digits indicating the nominal electrode efficiency (see p. 348) included only if this is equal to, or greater than 110, the figures being rounded off to the nearest multiple of 10, those of 5 and upwards being rounded up.

(2) a digit indicating the recommended welding positions for the electrode:
1 – all positions,
2 – all positions except vertical/down,
3 – flat and for fillet welds, horizontal/vertical,
4 – flat,
5 flat, vertical/down and, for fillet welds, horizontal/vertical,
9 any other position or combination of positions not classified above.

(3) a digit indicating the power requirements (Table 4)

(4) a letter H, where appropriate, indicating a hydrogen controlled electrode (see below).

Hydrogen-controlled electrodes. The coding is followed by the letter H if the electrode is hydrogen controlled. For this coding the electrodes deposit not more than 15 ml of diffusible hydrogen per 100 g of deposited weld metal when determined in accordance with the method given in BS 6693, Part 2. The manufacturer shall provide information on the recommended drying conditions to obtain hydrogen levels in the following ranges:

not exceeding 15 ml
not exceeding 10 ml } per 100 g of deposited weld metal.
not exceeding 5 ml

Examples of the use of BS 639 classification
Note: the tables referred to in Examples 1–3 are on pp. 359 and 360.

Example 1
Complete classification of electrode considered E 43 2 2 RR (2 1)

	STC code
E	Arc welding electrode
43	Strength 430–550 N/mm² (Table 1)
2	Temperature for minimum average impact strength of 28 J, 0 °C (Table 2)
2	Temperature for minimum average impact strength of 47 J, 0 °C (Table 3)
RR	Covering, rutile heavy coated (see list of coverings)
	Additional code
2	Welding position: all positions except vertical/down (see list of welding positions)
1	Welding current and voltage: a.c., 50 V; d.c. electrode +/– (Table 4)

Example 2

Complete classification of electrode considered E 51 5 4 B (120 1 0 H)

STC code

E	Arc welding electrode
51	Strength 510 650 N/mm² (Table 1)
5	Temperature for minimum average impact strength of 28 J, −40 °C (Table 2)
4	Temperature for minimum average impact strength of 47 J, −30 °C (Table 3)
R	Covering, basic (see list of coverings)

Additional code

120	Efficiency
1	Welding position: all positions (see list of welding positions)
0	Welding current and voltage: polarity d.c. as recommended by makers Not suitable for use on a.c. (Table 4)
H	Hydrogen controlled

Example 3

Complete classification of electrode considered E 51 5 3 BB (160 3 6 H)

STC code

E	Arc welding electrode
51	Strength 510–650 N/mm² (Table 1)
5	Temperature for minimum average impact strength of 28 J, −40 °C (Table 2)
3	Temperature for minimum average impact strength of 47 J, −20 °C (Table 3)
BB	Covering, basic, high efficiency (see list of coverings)

Additional code

160	Efficiency
3	Welding position: flat and for fillets, horizontal/vertical (see list of welding positions)
6	Welding current and voltage: a.c., 70 V; d.c. electrode + (Table 4)
H	Hydrogen controlled

Table 1. *Tensile properties*

Electrode designation	Tensile strength N/mm^2	Minimum yield stress N/mm^2	Minimum elongation % When digit of Table 2 is 0 or 1	When digit of Table 2 is 2	When digit of Table 2 is 3, 4, or 5
E 43	430–550	330	20	22	24
E 51	510–650	360	18	18	20

Table 2. *First digit for impact value*

Digit (in position in the classification)	Temperature for minimum average impact value of 28 J using 4 mm diameter electrodes only, °C
E -- 0 --	not specified
E -- 1 --	+20
E -- 2 --	0
E -- 3 --	−20
E -- 4 --	−30
E -- 5 --	−40

Table 3. *Second digit for impact value*

Digit (in position in the classification)	Temperature for minimum average impact value of 47 J using 4 mm diameter electrodes and the largest diameter electrodes submitted for classification, °C
E -- - 0	not specified
E -- - 1	+20
E -- - 2	0
E -- - 3	−20
E -- - 4	−30
E -- - 5	−40
E -- - 6	−50
E -- - 7	−60
E -- - 8	−70

Table 4. *Welding current and voltage conditions*

Digit	Direct current recommended electrode polarity	Alternating current minimum open circuit voltage, V
0	polarity as recommended by the manufacturer	not suitable for use or
1	+ or −	50
2	−	50
3	+	50
4	+ or −	70
5	−	70
6	+	70
7	+ or −	80
8	−	80
9	+	80

Table 5. *Types of electrode flux coverings*

Class	Composition of covering	Characteristics
C cellulosic	Organic materials containing cellulose $(C_6H_{10}O_5)_n$	Voluminous gas shield; good penetration; fast welding speeds; easily removable slag. Suitable for steel welding a.c. or d.c. electrode +ve. Used for first (stringer) run in downhill pipe-line welding. High level of hydrogen.
B basic	Calcium carbonate ($CaCO_3$), calcium fluoride (CaF_2) and other basic carbonates	The calcium carbonate decomposes in the arc heat to release carbon dioxide which gives the gas shield. The calcium oxide (CaO) combines with the calcium fluoride to form a basic slag having a low melting point. The low hydrogen content of the weld metal results in a weld that is resistant to solidification cracking and to a high sulphur content in the steel. Because there are no organic or hydrated materials in the covering the electrodes can be baked at high temperature giving a low level of hydrogen in the weld metal and reducing the danger of cold cracking, particularly in highly restrained joints and thick sections. Because of the relatively small gas shield, a short arc should be used and the electrodes are suitable for a.c. or d.c. electrode +ve. They should be stored under warm dry conditions and preferably baked before use.
BB basic high efficiency	Similar to basic electrode covering but have additional metallic materials (e.g. iron powder) in the covering which raise the efficiency to 130% and more	These electrodes are suitable for welding in the flat and horizontal/vertical position with a greatly increased rate of metal deposition. Their high efficiency covering makes them unsuitable for welding in the vertical and overhead positions. They can be used either a.c. or d.c., generally with electrode +ve. Efficiency is indicated by a three-figure digit beginning the additional coding.

Class	Composition of covering	Characteristics
R rutile	Titanium dioxide (rutile) and other hydrated minerals and/or organic cellulose materials	Easy to use, with a smooth weld finish and medium penetration. High level of hydrogen in the weld metal limits their use in thick sections or restrained joints. Suitable for a.c. or d.c.; the fast freezing of weld metal and fluid slag makes them suitable for vertical and overhead welding.
RR rutile heavy coating	Similar covering to the previous rutile electrode but containing, in addition, metallic substances (e.g. iron powder), which raise the efficiency to 130% or more.	Similar characteristics to rutile electrodes but generally unsuitable for vertical and overhead welding because of increased slag. Increased rate of metal deposition. Efficiency is indicated by a three-figure digit beginning the additional coding.
S other types		This class includes electrodes that do not fall into any of the previous classes. They range from little used types, such as those with acid covering (containing oxides and carbonates of lime and manganese with deoxidizers such as ferromanganese), to the oxide types (containing iron oxide with or without manganese oxide and silicates). This class also includes any newly developed flux systems. Manufacturer's advice should be followed when using them.

Table 6. *AWS electrode classification*

AWS classification	Type of covering	Capable of producing satisfactory welds in position shown[a]	Type of current[b]
E60 series electrodes			
E6010	High cellulose sodium	F, V, OH, H	DCEP
E6011	High cellulose potassium	F, V, OH, H	AC or DCEP
E6012	High titania sodium	F, V, OH, H	AC or DCEN
E6013	High titania potassium	F, V, OH, H	AC or DC, either polarity
E6020	High iron oxide	H-fillets	AC or DCEN
E6022[c]	High iron oxide	F	AC or DC, either polarity
E6027	High iron oxide, iron powder	H-fillets, F	AC or DCEN
E70 series electrodes			
E7014	Iron powder, titania	F, V, OH, H	AC or DC, either polarity
E7015	Low hydrogen sodium	F, V, OH, H	DCEP
E7016	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E7018	Low hydrogen potassium, iron powder	F, V, OH, H	AC or DCEP
E7024	Iron powder, titania	H-fillets, F	AC or DC, either polarity
E7027	High iron oxide, iron powder	H-fillets, F	AC or DCEN
E7028	Low hydrogen potassium, iron powder	H-fillets, F	AC or DCEP
E7048	Low hydrogen potassium, iron powder	F, OH, H, V-down	AC or DCEP

Note the American use of AC and DC for alternating current and direct current.

[a] F = flat, H = horizontal, H-fillets = horizontal fillets, V-down = vertical down.

$\left.\begin{array}{r}\text{V = vertical}\\ \text{OH = overhead}\end{array}\right\}$ for electrodes 3/16 in and under, except 5/32 in and under for classifications E7014, E7015, E7016, E7018.

[b] DCEP direct current electrode positive (DC reverse polarity). DCEN direct current electrode negative (DC straight polarity).

[c] E6022 classification electrodes are for single-pass welds.

Electrode classification (American)

American Welding Society (AWS) electrode classification: abridged specification for covered carbon steel arc welding electrodes ANSI*/AWS A5 1 81 (Reprint 1984)

In the AWS classification a four-digit number is used, preceded by the letter E (indicating a covered arc welding electrode).

The first two digits indicate the minimum tensile strength of the weld metal deposited in thousands of pounds force per square inch (1000 psi) (Table 6). For example, E70XX could represent an electrode giving weld metal having a minimum tensile strength of 72 000 psi or 72 ksi (500 MPa or 500 N/mm^2). Details of chemical composition, mechanical usability and soundness (radiographic) test, all-weld-metal tension test and impact (Charpy) test are given in the specification.

The last two digits indicate the characteristics of the covering (see Table 7).

Examples of AWS classification

Example 1

E6013: Electrode with weld metal tensile strength 60 ksi or 412 N/mm^2 high rutile covering bonded with potassium silicate AC or DC either polarity.

Table 7. *Characteristics of coverings*

Exx10	High cellulose, bonded with sodium silicate. Deeply penetrating, forceful spray-type arc. Thin friable slag.
Exx11	Similar to Exx10 but bonded with potassium silicate to allow use on AC or DC; covering bonded with sodium silicate.
Exx12	High rutile. Quiet arc, medium penetration.
Exx13	Similar to Exx12 but bonded with potassium silicate and other easily ionized materials. Fluid slag, easily removed.
Exx14	Similar to Exx12 and Exx13 types with the addition of iron powder.
Exx15	Basic low hydrogen type bonded with sodium silicate. For high tensile steels.
Exx16	Similar to Exx15 but bonded with potassium silicate.
Exx18	Covering similar to Exx15 and Exx16 but with addition of iron powder.
Exx20	High iron oxide coating bonded with sodium silicate.
Exx24	Similar to Exx12 and Exx13. Heavily coated plus iron powder.
Exx27	Flux ingredients similar to Exx20 with the addition of iron powder.
Exx28	Similar to Exx18 but with heavier covering. Low hydrogen, potassium silicate as binder. Flat and horizontal fillets.
Exx48	Similar to Exx28, low hydrogen but suitable for most positions.

* American National Standards Institute

Example 2

E7018: Electrode with weld metal of tensile strength 70 ksi, with basic covering, iron powder, low hydrogen. Bonded with potassium silicate F, V, OH, H, AC or DCEP.

Core wire for all electrodes in this specification is usually of composition 0.10% carbon, 0.45% manganese, 0.03% sulphur, 0.02% phosphorus and 0.01% silicon.

Welders' accessories (Fig. 8.10*a*)

Electrode holder

This is an arrangement which enables the welder to hold the electrode when welding. It has an insulated body and head which reduces the danger of electric shock when working in damp situations and also reduces the amount of heat conducted to the hand whilst welding. The electrode is clamped between copper jaws which are usually spring loaded, and a simple movement of a side lever enables the electrode to be changed easily and quickly. In another type the electrode end fits into a socket in the holder head and is held there by a twist on the handle. The welding flexible cable is attached to the holder by clamping pieces or it may be sweated into a terminal lug. The holder should be of light yet robust construction and well insulated, and electrode changing must be a simple operation. Fig. 8.10*b* shows typical holders.

Head shields, lenses and general protective gear. The rays from the metallic arc are rich in infra-red and ultra-violet radiation, and it is essential that the eyes and face of the welder should be protected from these rays and from the intense brightness of the arc. The welding shield can either fit on to the head (Fig. 8.11*a*), leaving both hands free, or may be carried in one hand. It should extend so as to cover the sides of the face, especially when welding is done in the vicinity of other welders, so as to prevent stray flashes reaching the eyes. The shield must be light and, thus, preferably made of fibre.

Helmets and hand shields are now available, weighing little more than ordinary shields, that give maximum comfort when welding in restricted conditions. They are similar in appearance to the standard shield but have double-wall construction, the inner face being perforated with small holes, through which pure air is supplied to the interior of the helmet. Head and face are kept cool and the operator's eyes and lungs are protected from dust and fumes as well as radiation and spatter as with ordinary shields. The air is supplied from any standard compressor or air line, the supply tube being fitted with a pressure-reducing valve to give a pressure of 1.7 bar (Fig. 8.11*b*)

The arc emits infra-red and ultra-violet radiation in addition to light in the visible spectrum. The filter or lens is designed to protect the eyes from the ultra-violet and infra-red radiation which would injure the eyes and also to reduce the amount of visible light so that there is no discomfort. The filters are graded by numbers, followed by the letters EW (electrical welding) denoting the process, according to BS 679, and increase in shade depth with increasing number of increasing currents. The filters recommended are: up to 100 A, 8 or 9/EW; 100–300 A, 10 or 11/EW; over 300 A,

Fig. 8.10. (*a*)

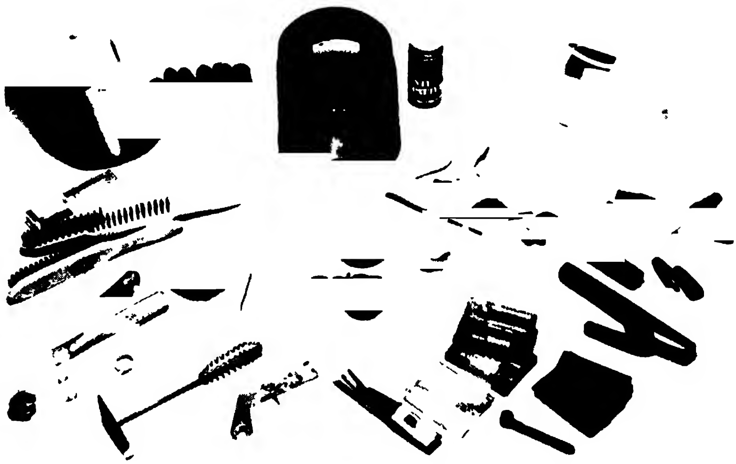


Fig. 8.10. (*b*)

Fig. 8.11. (*a*)

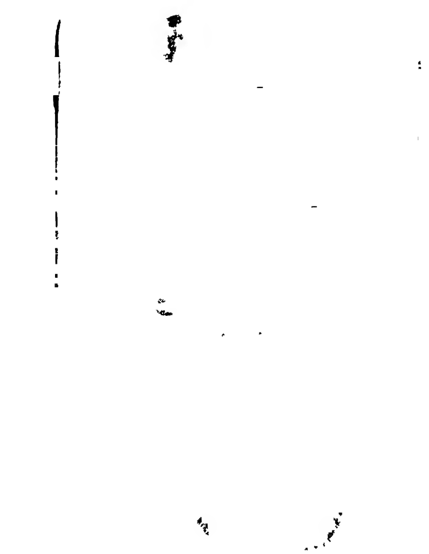
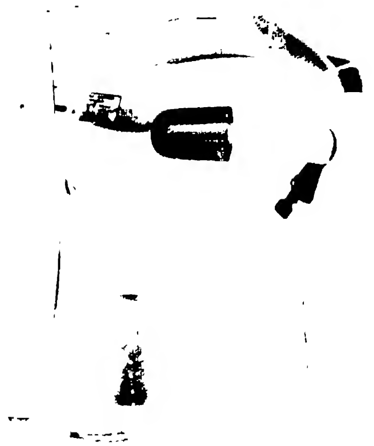


Fig. 8.11 (*b*)



12, 13, 14/EW.* The choice of the correct filter is the safeguard against eye damage. Occasional accidental exposure to direct or reflected rays may result in the condition known as arc flash. This causes no permanent damage but is painful, with a feeling of sand in the eyes accompanied by

* Many headshields are now fitted with light-reactant lenses, leaving both hands free. The normal view that the welder has before welding is quite clear. Upon the arc being struck, the lens darkens to the shade previously selected, the time lag being of the order of 0.001–0.0015 sec.

watering. Bathing the eyes with eye lotion and wearing dark glasses reduces the discomfort and the condition usually passes with no adverse effects in from 12 to 24 hours. If it persists a doctor should be consulted.

A lens of this type is expensive and is protected from metallic spatter on *both* sides by plain glass, which should be renewed from time to time, as it becomes opaque and uncleanable, due to spatter and fumes.

The welding area must be adequately screened so that other personnel are not affected by rays from the arc.

The eyes must also be protected against foreign bodies such as particles of dust and metal, which are all potential dangers in the welding shop.

Spectacles with clear or tinted lenses are available and also fit over normal spectacles if required. For use particularly on grinding operations there are clear goggles and there are also face shields with plain or tinted visors which fit on the head like a welding head mask but have the shield hinged so that it is easily raised when required. For conditions where there is much noise there are hearing protectors which fit snugly over the ears in the same way as radio headphones. There are also ear plugs which are made in a soft foam and which are easily inserted, and are very effective.

Protection against inhalation of polluted atmosphere is given by single cartridge dust respirators and various types of moulded plastic masks with adjustable headbands in which the filter is replaceable. A protective cap is also available with a hard shell, foam lining and elastic grip giving good fitting to the head.

Leather or skin aprons are excellent protection for the clothes against sparks and molten metal. Trouser clips are worn to prevent molten metal lodging in the turn-ups, and great care should be taken that no metal can drop inside the shoe, as very bad burns can result before the metal can be removed. Leather spats are worn to prevent this. Gauntlet gloves are worn for the same reason, especially in vertical and overhead welding. In welding in confined spaces, the welder should be fully protected, so that his clothes cannot take fire due to molten metal falling on him, otherwise he may be badly burnt before he can be extracted from the confined space.

The welding bench in the welding shop should have a flat top of steel plate, about 1.5 m × 0.75 m being a handy size. On one end a vice should be fitted, while a small insulated hook on which to hang the electrode holder when not in use is very handy.

Jigs and fixtures

These are a great aid to the rapid setting up of parts and holding them in position for welding. In the case of repetition work they are essential equipment for economical working. Any device used in this way

comes under this heading, and jigs and fixtures of all types can be built easily, quickly and economically by arc welding. They are of convenience to the welder, reduce the cost of the operation, and standardize and increase the accuracy of fabrication.

Jigs may be regarded as specialized devices which enable the parts being welded to be easily and rapidly set up, held and positioned. They should be rigid and strong since they have to stand contractional stresses without deforming unless this is required; simple to operate, yet they must be accurate. Their design must be such that it is not possible to put the work in them the wrong way, and any parts of them which have to stand continual wear should be faced with wear-resistant material. In some cases, as in inert gas welding (q.v.), the jig is used as a means of directing the inert gas on to the underside of the weld (backpurge) and jigs may also incorporate a backing strip.

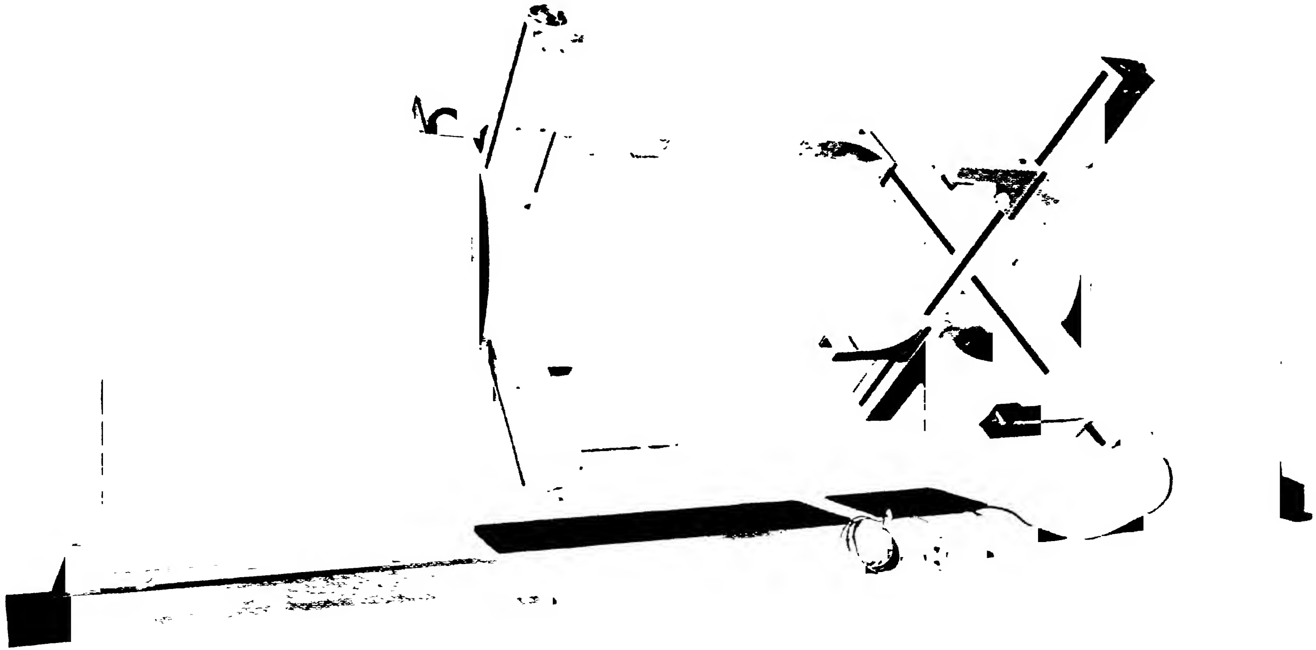
Fixtures are of a more general character and not so specialized as jigs. They may include rollers, clamps, wedges, etc., used for convenience in manipulation of the work. Universal fixtures are now available, and these greatly reduce the amount of time of handling of the parts to be welded and can be adapted to suit most types of work.

Manipulators, positioners, columns and booms

Positioners are appliances which enable work to be moved easily, quickly and accurately into any desired position for welding – generally in the downhand position since this speeds up production by making welding easier, and is safer than crane handling. Universal positioners are mounted on trunions or rockers and can vary in size from quite small bench types to very large ones with a capacity of several tons. Manually operated types are generally operated through a worm gearing with safety locks to prevent undesired movement after positioning. The larger types are motor-driven, and on the types fitted with a table, for example, the work can be swung through any angle, rotated, and moved up and down so that if required it can be positioned under a welding head.

As automatic welding has become more and more important so has the design of positioners and rollers improved. Welding-columns and booms may be fixed or wheel mounted and have the automatic welding head mounted on a horizontal boom which can slide up and down a vertical column. The column can be swivel mounted to rotate through 360° and can be locked in any position. In the positioning ram-type boom there is horizontal and vertical movement of the boom carrying the welding head and they are used for positioning the head over work which moves beneath them at welding speed. In the manipulating ram-type boom, the boom is

Fig. 8.12. (*a*) Head and tailstock manipulator



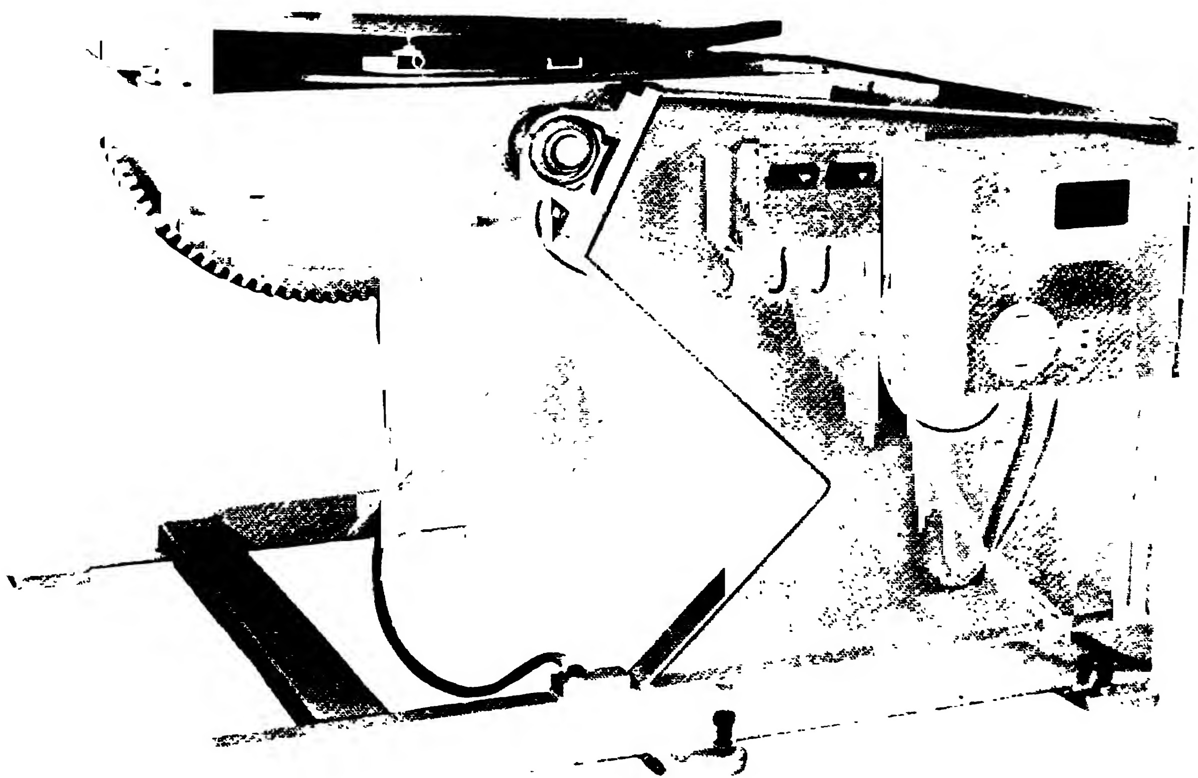


Fig. 8.12. *(b)* Power rotation, power tilt through 135

Fig. 8.12. (*c*) Roller bed, travelling type, motorized

Fig. 8.12. (*d*) Power rotation, manual tilt

provided with a variable speed drive of range of about 150–1500 mm per min enabling the boom to move the welding head over the stationary work. Both types of boom in the larger sizes can be equipped with a platform to carry the operator, who can control all movements of head and boom from this position in Fig. 8.12. Various types are shown.

*The practice of manual metal arc welding**

Electrode lengths. The actual length must be within ± 2 mm of the nominal value

Diameter, mm	Nominal length, mm
1.6	200
	250
2.0	200
	250
	300
	350
2.5	250
	300
	350
3.2, 4.0 or 5.0	350
	450
6.0 to 8.0	350
	450
	500
	600
	700
	900

Electrode diameter mm	Electrode diameter inch	Nearest fractional equivalent, in.
1.6	0.06	—
2.0	0.08	$\frac{5}{64}$
2.5	0.10	$\frac{3}{32}$
3.0	0.12	—
3.2	0.13	$\frac{1}{8}$
4.0	0.16	$\frac{5}{32}$
5.0	0.19	$\frac{3}{16}$
6.0	0.23	—
6.3	0.25	$\frac{1}{4}$
8.0	0.32	$\frac{5}{16}$

* American designation: shielded metal arc welding (SMAW).

Safety precautions

Protection of the skin and eyes. Welding gloves should be worn and no part of the body should be exposed to the rays from the arc otherwise burning will result. Filter glasses (p.368) should be chosen according to BS recommendations. Where there are alternatives the lower shade numbers should be used in bright light or out of doors and the higher shade numbers for use in dark surroundings.

Do not weld in positions where other personnel may receive direct or reflected radiation. Use screens. If possible do not weld in buildings with light coloured walls (white) as this increases the reflected light and introduces greater eye strain.

Do not chip or deslag metal unless glasses are worn.

Do not weld while standing on a damp floor. Use boards.

Switch off apparatus when not in use.

Make sure that welding return leads make good contact, thus improving welding conditions and reduced fire risk.

Avoid having inflammable materials in the welding shop.

Degreasing, using chemical compounds such as trichlorethylene, perchlorethylene, carbon tetrachloride or methyl chloride, should be carried out away from welding operations, and the chemical allowed to evaporate completely from the surface of the component before beginning welding. The first-named compound gives off a poisonous gas, phosgene, when heated or subjected to ultra-violet radiation, and should be used with care. Special precautions should be taken before entering or commencing any welding operations on tanks which have contained inflammable or poisonous liquids, because of the risk of explosion or suffocation. The student is advised to study the following publications of the Department of Employment (SHW-Safety, health and welfare):

SHW 386. *Explosions in drums and tanks following welding and cutting*. HMSO.

SHW Booklet 32. *Repair of drums and tanks. Explosions and fire risks*. HMSO.

SHW Booklet 38. *Electric arc welding*. HMSO.

Memo No 814. *Explosions Stills and tanks*. HMSO.

Technical data notes No. 18. *Repair and demolition of large storage tanks*. No. 2. *Threshold limit values*. HMSO.

Health and safety in welding and allied processes. The Welding Institute.

Filters for use during welding. BS 679. British Standards Institution.

Protection for eyes, face and neck. BS 1542. British Standards Institution.

Metal arc welding

This section on practical welding techniques applies equally well to all the following steels:

BS 970 *Wrought steels for mechanical and engineering purposes*
Part 1: *General inspection and testing procedures and specific requirements for carbon, carbon manganese, alloy and stainless steel.*

BS 1501 Part 1: *Steel for fired and unfired pressure vessels*
Part 2: *Aluminium steel for fired and unfired pressure vessels.*

In each and every case the electrode recommended by the manufacturer for the particular steel being welded should be used and the procedure advised for the electrode (such as pre- or post-heat) strictly adhered to.

Sources of supply. The source of welding supply can be a.c. or d.c. The relatively cheap a.c. sets with an output maximum of about 150 A are extremely useful for repair and maintenance in small workshops, but are used mainly for steel. Larger a.c. sets are available for fabrication shops including shipyards.

The d.c. output units are used for both steel and non-ferrous metals and can be obtained in current ranges of 300 A, 400 A, as required. The latest sets have thyristor controlled rectifiers with a one knob stepless control of current, and a remote control can also be supplied.

In order to assist the operator, tables are given indicating the approximate current values with various types and sizes of electrodes. These tables are approximate only and the actual value of the current employed will depend to a great extent upon the work. In general the higher the current in the range given for one electrode size, the deeper the penetration and the faster the rate of deposit. Too much current leads to undercutting and spatter. Too small a current will result in insufficient penetration and too small a deposit of metal. As a general rule, slightly increase the arc voltage as the electrode size increases. The angle of the electrode can be varied between 60° and 90° to the line of the weld. As the angle between electrode and plate is reduced, the gas shield becomes less effective, the possibility of adverse effects of the atmosphere on the weld increases, and penetration is reduced.

Full details of currents suitable for the particular electrodes being used are usually found on the electrode packet and should be adhered to; in the following pages it is assumed that, if a.c. is being used, no notice should be taken of the polarity rules, and covered electrodes only should be used.

The techniques of welding mild steel and low-alloy steel are similar.

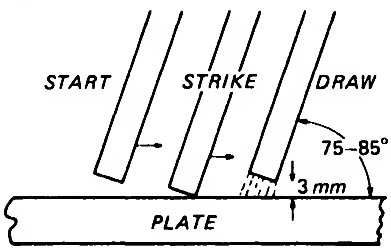
Diameter of rod (mm)	Current (amperes) Min.	Max.	Average
1.6	25	45	40
2.0	34	65	50
2.5	50	90	90
3.2	60	130	115
4.0	100	180	140
5.0	150	250	200
6.0	200	310	280
6.3	215	350	300
8.0	250	500	350

Note. American designation: straight polarity, electrode −ve, DCEN; reverse polarity, electrode +ve, DCEP. These apply when welding with d.c.

Striking and maintaining the arc. With an electrode of 4 mm diameter and a current of 130–150 A and a mild steel plate 6–8 mm thick, the first exercise is to strike and maintain the arc. The operator should be comfortably placed with the cable to the electrode exerting no pull on the holder (e.g. cable over the operator's shoulder). The electrode tip is scratched on to the plate at the same time as the hand shield with filter glass is drawn across the face. Never expose eyes, face or any part of bare skin to arc flashes, as the effects can be most painful. The electrode is lifted to about 3 mm from the plate, drawing the arc, and the molten pool can be clearly seen (Fig. 8.13). The lighter, brighter colour is the slag while the more viscous, darker colour is the molten metal.

Straight runs on the plate can now be made once the arc can be struck and maintained. As the electrode melts it deposits the metal on the plate and this deposit should be in a straight line and continuous with no gaps or entrapped slag. Too high a current for a given size of electrode will result in

Fig. 8.13. Striking and maintaining the arc



the electrode becoming overheated and eventually red hot. A 4 mm electrode with about 160 A will deposit about 200–235 mm (about 9 in.) of weld metal, if the speed is correct. Slower travel will result in a wider run and it will not be so long, while faster travel results in a longer and narrower bead with the danger of gaps and slag inclusions. The fault of most beginners is that the run is made too quickly. The depth of the crater indicates the amount of penetration (Fig. 8.14*a*).

If, when striking the arc or welding, the electrode touches the plate and 'freezes' it should be freed with a sharp twist of the holder. If this fails, switch off the electric supply at the set and remember that the electrode will still be very hot.

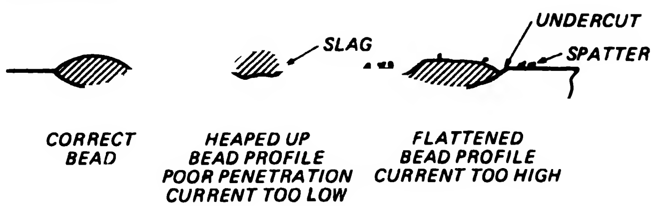
When welding with a d.c. machine, considerable difference can be seen according to whether the electrode is made positive or negative polarity. Since greater heat is generated at the positive pole, making the electrode negative reduces the burn-off rate and deepens the crater and thus the penetration. With the electrode positive the penetration is reduced but the burn-off rate is increased, most heat being generated near the electrode. For this reason (together with the type of electrode coating) most special steels (stainless, heat resistant, etc.), vertical and overhead runs in steel, cast iron and aluminium and bronze are nearly always welded with electrode positive. The instructions on the electrode package issued by the makers should be strictly adhered to.

It will be noticed that when welding on a cold plate the deposited bead rises well above the level of the metal when it is cold. As welding progresses, however, and the parent metal gets heated up, the penetration becomes deeper and the head has a lower contour. For this reason the current setting can be higher when welding is commenced and then should be reduced slightly as the metal heats up, resulting in a bead having an even contour throughout its length.

This exercise should be continued until a straight, even, uniform bead about 250 mm long can be run with good penetration.

If a bead is to be continued after stopping, as for example to change an

Fig. 8.14. (*a*)



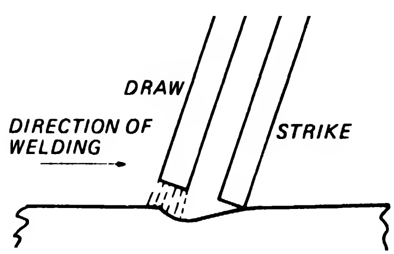
electrode, the end of the bead and the crater must be deslagged and brushed clean and the arc struck at the forward end of the crater. The electrode is then quickly moved to the rear end and the bead continued, so that no interruption can be detected (**Fig. 8.14*b***). This should be practised until no discontinuity in the finished bead can be observed. Since in welding long runs, the welder may have to change rods many times, the importance of this exercise will be appreciated, otherwise a weakness or irregularity would exist whenever the welding operation was stopped.

Beads can now be laid welding away from the operator and also welding from left to right or right to left. A figure-of-eight about 120 mm long provides good practice in this and in changing direction of the bead when welding. The bead should be laid continuously around the figure.

A transformer unit usually has two voltage settings, one 80 open circuit volts and the other 100 OCV, the latter being used for thinner sheet when the current setting is low. Other sets may have lower OCV's, the figure required generally being given on the electrode packet. With an a.c. volts setting of 80 V the current setting for a given electrode can be varied from a low value, giving poor penetration and a shallow crater, with the metal heaping up on the plate producing overlap, to a high value, giving an excessively deep crater, too much penetration with a fierce hissing and not well controllable arc, much spatter, and a flat bead with undercut and an overheated electrode. Intermediate between these extreme values is a correct value of current, say 115–125 A for a 3.2 mm electrode. There is good penetration, the metal flows well, the arc is controllable with no spatter or undercut, and the arc sound is a steady crackle.

These results are tabulated below. If a d.c. set is being used with a voltage control this also can be varied for the operator to find out the effect of this control.

Fig. 8.14 (*b*) Arc struck in front of crater and moved back to continue the run preserves weld profile and helps eliminate any start porosity



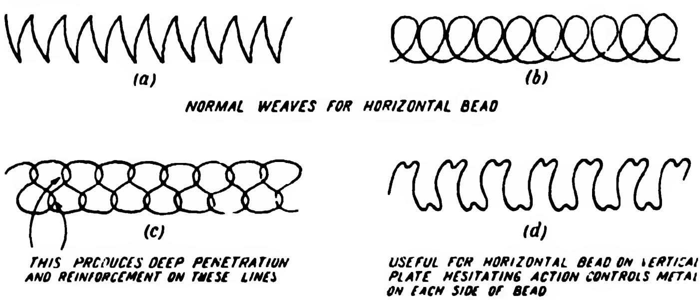
Welding circuit	Effect
Too low current	Poor penetration; shallow crater; metal heaps up on plate with overlap; arc has unsteady spluttering sound.
Too high current	Deep crater; too deep penetration; flat bead; fierce arc with loud crackle; electrode becomes red hot; much spatter.
Too high voltage	Noisy hissing arc; fierce and wandering arc; bead tends to be porous and flat; spatter.
Correct voltage and current and welding speed	Steady crackle; medium crater giving good penetration; easily controlled stable arc; smooth even bead.

Weaving (see pp. 474–6 for automatic weaving)

This may be attempted before or after the preceding exercise according to the inclination of the operator. Weaving is a side to side motion of the electrode, as it progresses down the weld, which helps to give better fusion on the sides of the weld, and also enables the metal to be built up or reinforced along any desired line, according to the type of weave used. It increases the dilution of weld metal with parent metal and should be reduced to a minimum when welding alloy steel.

There are many different methods of weaving, and the method adopted depends on the welder and the work being done. The simplest type is shown in **Fig. 8.15*a***, and is a simple regular side to side motion, the circular portion helping to pile the metal in the bead in ripples. **Fig. 8.15*b*** is a circular motion favoured by many welders and has the same effect as **Fig. 8.15*a***. Care should be taken with this method when using heavy coated rods that the slag is not entrapped in the weld. **Fig. 8.15*c*** is a figure-of-eight method and gives increased penetration on the lines of fusion, but care must again be taken that slag is not entrapped in the overlap of the weave on the edges. It is useful when reinforcing and building up deposits of wear-

Fig. 8.15



resisting steels. **Fig. 8.15*d*** is a weave that is useful when running horizontal beads on a vertical plane, since by the hesitating movement at the side of the bead, the metal may be heaped up as required. The longer the period of hesitation at any point in a weave, the more metal will be deposited at this point.

Weaving should be practised until the bead laid down has an even surface with evenly spaced ripples. The width of the weave can be varied, resulting in a narrow or wide bead as required.

Padding and building up shafts

This exercise provides a good test of continued accuracy in laying a weld. A plate of 8–9.5 mm mild steel about 150 mm square is chosen and a series of parallel beads are laid side by side across the surface of the plate and so as to almost half overlap each other. If the beads are laid side by side with no overlap, slag becomes entrapped in the line where the beads meet, being difficult to remove and causing blowholes **(Fig. 8.16)**. Each bead is

Fig. 8.16

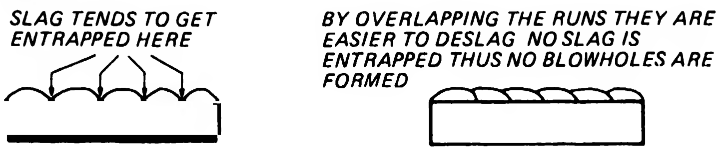
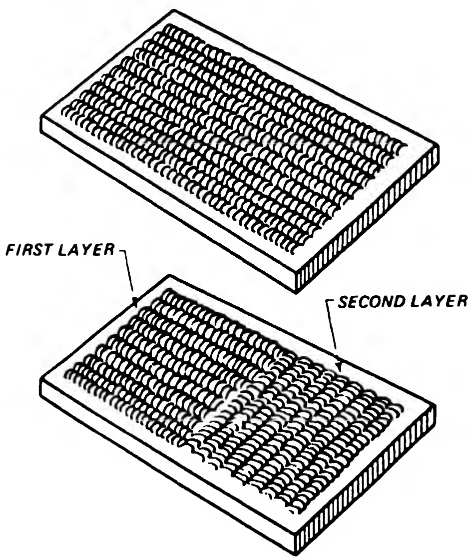


Fig. 8.17



deslagged before the next is laid. The result is a build-up layer of weld metal.

After thoroughly cleaning and brushing all slag and impurities from this layer, another layer is deposited on top of this with the beads at right angles to those of the first layer **(Fig. 8.17)**, or they may be laid in the same direction as those of the first layer. This can be continued for several layers, and the finished pad can then be sawn through and the section etched, when defects such as entrapped slag and blowholes can at once be seen.

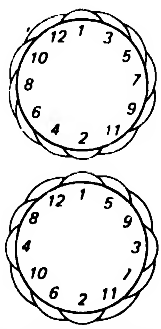
Odd lengths of steel pipe, about 6 mm or more thick, may be used for the next exercise, which again consists in building up layers as before. The beads should be welded on opposite diameters to prevent distortion **(Fig. 8.18*a*)**. After building up two or more layers, the pipe can be turned down on the lathe and the deposit examined for closeness of texture and absence of slag and blowholes. Let each bead overlap the one next to it as this greatly reduces the liability of pin-holes in the finished deposit

The same method is adopted in building up worn shafts and a weld may be run around the ends as shown to finish the deposit. Another method sometimes used consists of mounting the shaft on V blocks and welding spirally **(Fig. 8.18*a* and *b*)**.

Tack welding

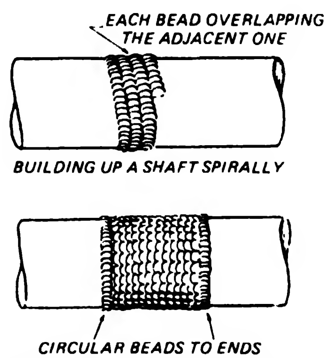
Tack welds are essential in welding and fabrication to ensure that there is correct gap and line-up of the components to be welded. The tack welds should be made with a higher current than normal to ensure good fusion and penetration and should be strong enough and of sufficient length and frequency of spacing to ensure rigidity against the distortional

Fig. 8.18 (*a*)



ALTERNATIVE METHODS OF LAYING SEQUENCE OF BEADS EACH BEAD IS DESLAGGED BEFORE THE OVERLAPPING LAYER IS RUN AND TAKE CARE THERE IS NO ENTRAPPED SLAG IN POCKETS

Fig. 8.18 (*b*)



NORMAL METHOD OF BUILDING UP

stresses set up in the welding process. The tack welds should be deslagged and examined for cracks, which may occur because of the rapid cooling of the tack weld if there is no pre-heat. If any cracks are found they should be gouged or ground out and the tack weld remade. Cracks left in may cause cracking in the finished weld.

Thicker plate may need stronger tack welds. These should be made in two runs, the second tack weld being made after the first has been deslagged and examined. Remember when making the first run that the tack weld must be fused into the run so that there is no evidence of the tack weld. This may mean welding at a slightly increased rate at these points. Tack welds are often made by the TIG process in fabrication of plate and pipe work for lining up and then welded by the MIG process.

Plates set up for fillet welding should have the tack welds made at about twice the frequency of pitch used for butt welds.

The operator should now be able to proceed to the making of welded joints, and it will be well to consider first of all the method of preparation of plates of various thicknesses for butt welding. Although a U preparation may prove to be more expensive than a V preparation, it requires less weld metal and distortion will be lessened. For thicker sections the split-weave or stringer bead technique is often used (**Fig. 8.21**) since the stresses due to contraction are less with this method than with a wide weave.

When a weld is made on a plate inclined at not more than 5° to the horizontal, this is termed the flat position, and wherever possible welding should be done in this position, since it is the easiest from the welder's point of view.

Fig. 8.19 shows some simple welding joints.

Butt welding in the flat position

Joints are prepared with an included angle of 60° with root face and root gap as required for the plate thickness. (An angle of 60° is chosen because *it combines accessibility to the bottom of the joint with the least* amount of weld metal (**Fig. 8.21**).)

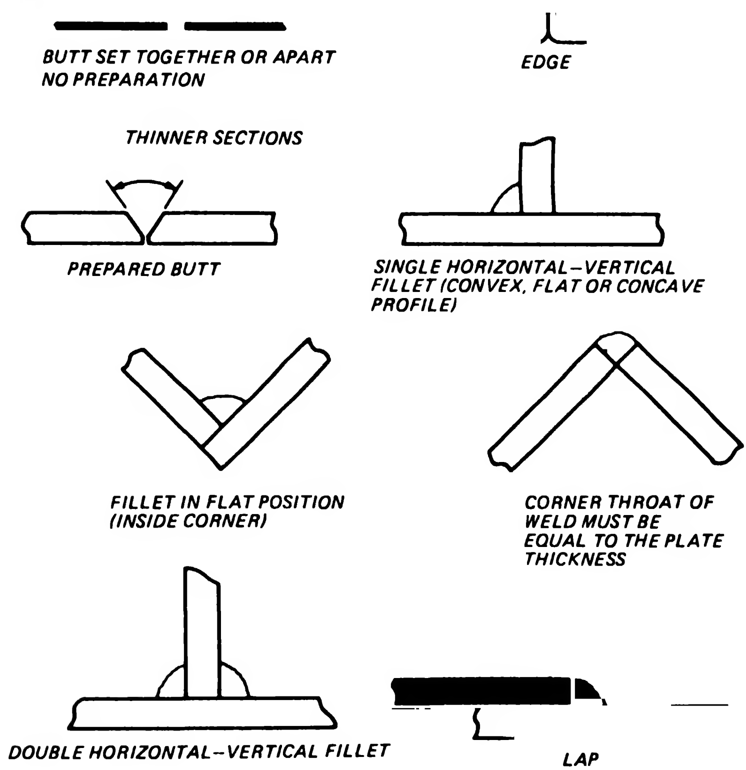
The plates can be tack welded in position to prevent movement due to expansion and contraction during welding and the tack welds must be strong enough to prevent movement of the plates. Using say a 4 mm electrode with about 125–135 A for a 3 mm gap and 160–170 A for a 1.5 mm gap the welds are kept to about 3–3.5 mm thickness. The length of the run depends upon the size of the electrode and the width of the weld, which gets greater as the joint is filled up. To avoid having the top deposits in thick plate too wide, the stringer or split-weave method is used. If the plates are to be welded from one side only, the penetration *must* be right through to the

bottom of the V and the underbead must be continuous along the length of the joint (Fig. 8.20). If a sealing run is to be made the underside of the joint should be back chipped (by electrically or pneumatically operated chipping hammer) so that any defects such as inclusions, porosity, etc., are removed and a sealing run is then made, using a rod about 5 mm diameter.

In many cases the joint to be welded is accessible from one side only, so that the penetration bead cannot be examined for defects and it is not possible to employ a sealing run. In this case a backing bar can be used. The plates are prepared to a sharp edge and the backing bar, usually about 25 mm wide and 5 mm thick, is tack welded to one plate and the plates set apart to the required gap. The first run is made with a higher current than previously used as there is no possibility of burn through. This ensures that the roots of the parent plate and the backing bar are well fused together, and the other runs are then made, as previously, with lower current.

Double V butt joint preparation is often used with thicker plate because

Fig. 8.19. Simple welding joints.



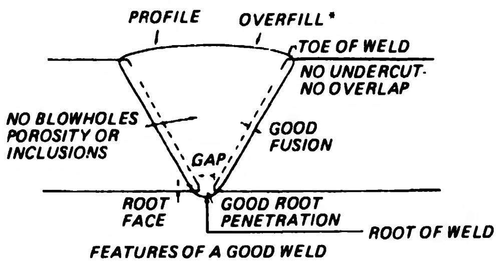
of the saving in weld metal, which in the case of a 19 mm ($\frac{3}{4}''$) plate is about half of that required for single-V preparation. The plates are prepared to a sharp edge (Fig. 8.21) and the first run made with little or no weave and absolutely continuous. The plates are turned over, the joint root deslagged, after which the next run is made on to the root of the first run, ensuring that there is no entrapped slag or porosity in the centre of the joint. The remaining runs can be made on alternate sides of the joint where possible, reducing the distortional stresses.

Butt welds on pipes provide good exercise in arc manipulation. The pipes are prepared in the same way as for plates by V'ing. They are then lined up in a clamp, or are lined up and tack welded in position and then placed across two V blocks.

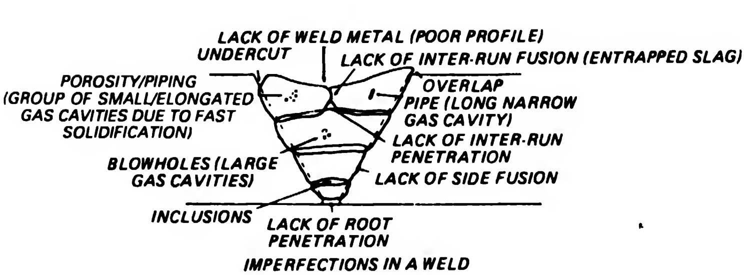
Right angle outside corner joints

Tack weld two 12.5 mm ($\frac{1}{2}$ in.) steel plates together with a 2 mm gap between them and an angle of 90° between the plates (Fig. 8.22), making a right angled corner joint. With an electrode of 4 mm diameter and

Fig. 8.20



(a)



(b)

* The BS term is 'excess weld metal' but the term 'overfill' is now used because in certain circumstances, such as under fatigue loading, excess weld metal (or overfill) is detrimental to the weld

about 160 A current make a run about 180 mm long keeping the electrode at an angle of about 60 and ensuring that penetration is adequate but not excessive. The speed of welding should be increased where the tack welds occur to ensure the uniform appearance of the upper side of the weld. Deslag upper and underside of the joint and observe that correct penetration has been achieved. Then make the second (and subsequent) runs with an electrode angle of about 70–75 using a slight weave and avoiding any undercut. Deslagging is followed by the final run to obtain the correct throat thickness and profile as shown. A sealing run can be made if required on the underside of the joint using a somewhat higher current.

Fig. 8.21. Flat butt welds, preparation

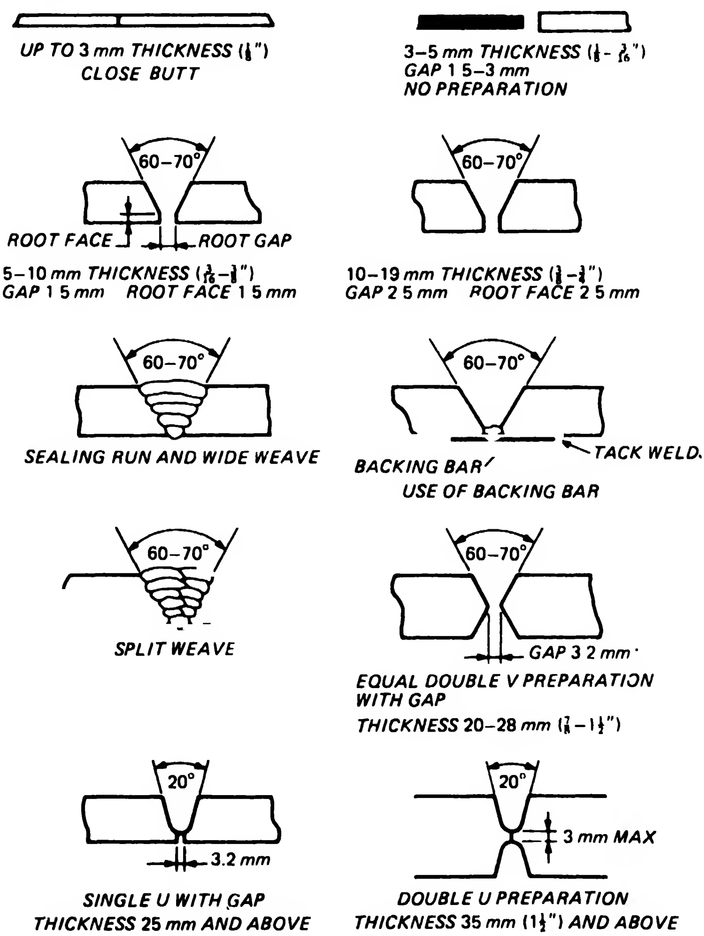
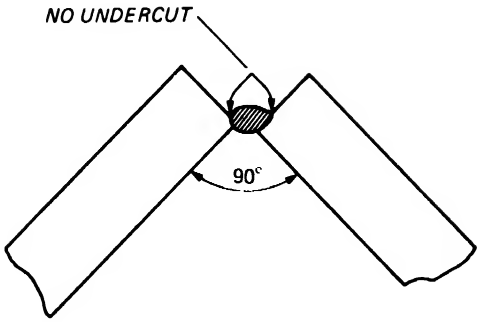
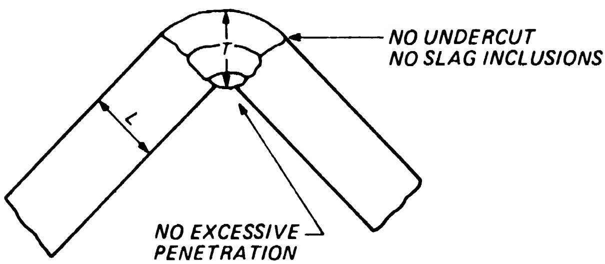


Fig. 8.22. Right angle corner welds

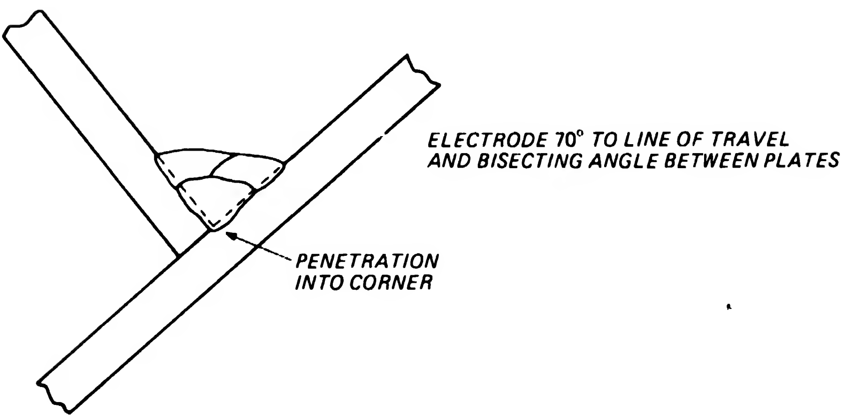


PLATES TACK WELDED IN POSITION AFTER DESLAGGING, FIRST RUN GIVES UNIFORM PENETRATION ON UNDERSIDE OF JOINT, TACK WELD MUST BE INCORPORATED INTO THE MAIN WELD, WITHOUT TRACE



THROAT THICKNESS EQUALS PLATE THICKNESS

Fig. 8.23. Fillet weld flat position.



Fillet welds in the flat position

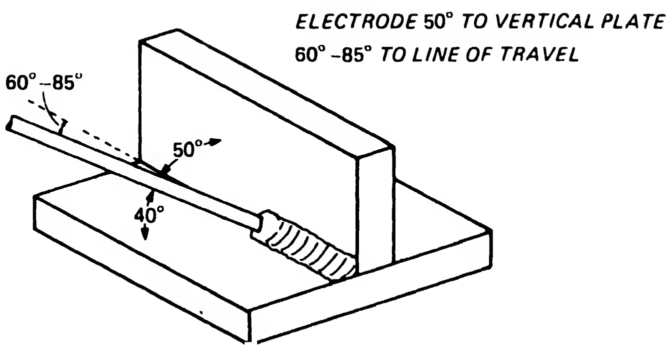
Two plates about 9 mm thick are tack welded to make a tee joint and set at an angle of 45° to the horizontal as shown in **Fig. 8.23.** The weld is made with the electrode at an angle of about 70° to the line of travel and bisecting the angle between the plates. The weld metal must penetrate and fuse into the corner of the joint and there must be no undercutting with equal leg length. A 5 mm electrode at about 200 A will give a 6 mm fillet (throat) about 280 mm long. Make sure that the tack welds, which have been previously deslagged and examined for cracks, etc., are well incorporated into the weld by slightly increasing the welding speed at these points.

Fillet welds in the horizontal–vertical position

With the one plate in the vertical position there will be more tendency for the weld metal to fall downwards to the horizontal plate. To counteract this the electrode is directed at about 40° to the horizontal plate and more vertically to the line of travel – say about 60–80° increasing with the rod diameter. Although the slag, which is more fluid, tends to fall to the horizontal plate, make sure that the weld has equal leg length and avoid the most common error of undercutting in the vertical plate **(Fig. 8.24).**

Electrode diam. (mm)	Fillet leg length (mm)	Length of run (mm)
3.25 ($\frac{1}{8}$ in.)	4	300 (12 in.)
4.0	5	300
6.0 ($\frac{1}{4}$ in.)	6.0	300

Fig. 8.24. Horizontal vertical fillet weld



Too long a length of run gives lack of root fusion and too small leg length. Too short a length of weld causes excessive undercut and uncontrolled slag trouble. Root penetration (Figs. 8.26*d* and 8.27) is essential, and avoid the other faults shown.

A lap joint is a particular case of a fillet weld. Take care not to cause breaking away of the edges as shown (Fig. 8.25). Fig. 8.26*a*, *b* and *c* shows various types of fillet welds while Fig. 8.26*e* shows profiles and definitions of leg and throat.

Fig. 8.25. Lap joint

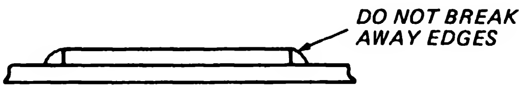
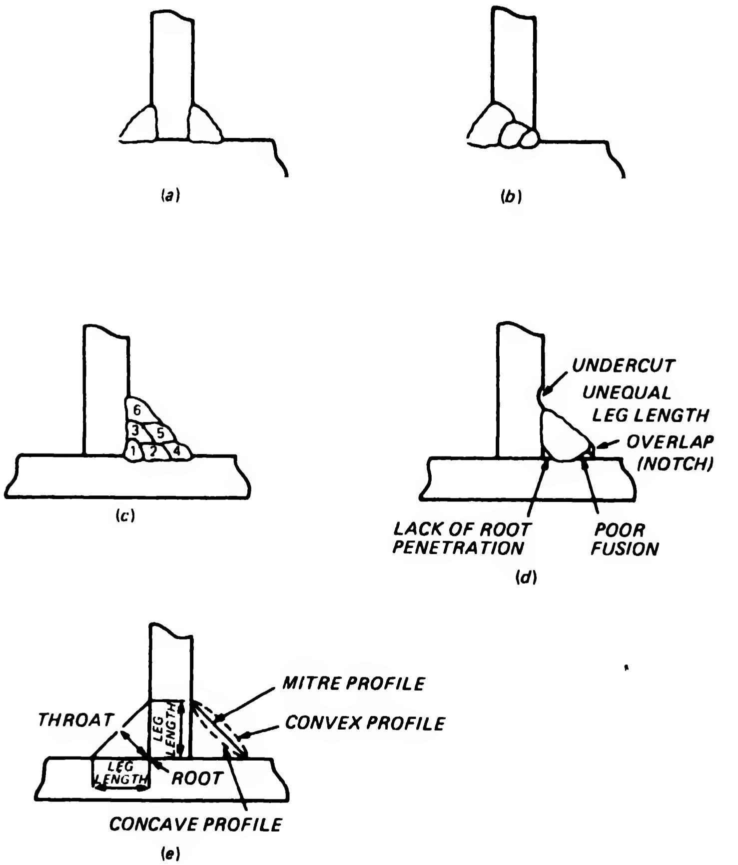


Fig. 8.26. Horizontal vertical fillet welds. (*a*) Double fillet, no preparation (*b*) Prepared fillet, welded one side only (*c*) Multi-run fillet, equal leg length (*d*) Faults in horizontal vertical fillet welds (*e*) Weld profiles



Special electrodes for fillet welding help greatly in producing welds having uniform surface, and good penetration with no undercut. Control of the slag often presents difficulties. Keeping the rod inclined at about 70° as before stated helps to prevent the slag running ahead of the molten pool. Too fast a rate of travel will result in the slag appearing on the surface in uneven thicknesses, while too slow a rate of travel will cause it to pile up and flow off the bead. Observation of the slag layer will enable the welder to tell whether his speed is correct or not.

The plain fillet or tee joint (**Fig. 8.19**) is suitable for all normal purposes and has considerable strength. The prepared fillet (**Fig. 8.26*b***) is suitable for heavier loads, and is welded from one side only.

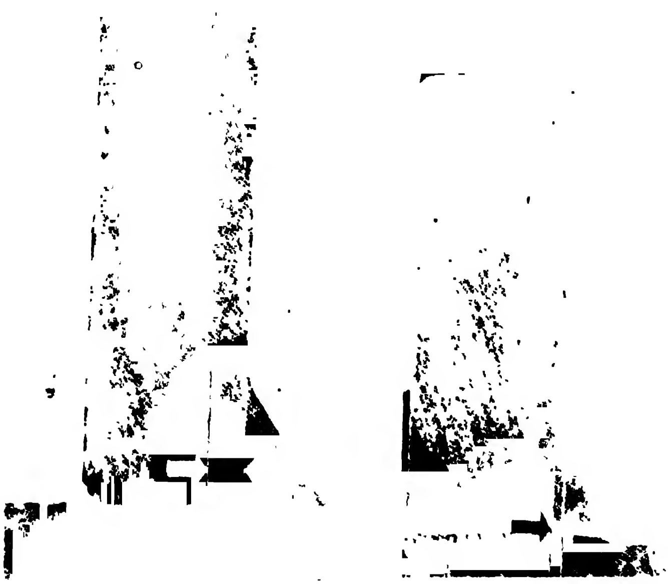
In thick sections a thinner electrode is used for the first bead, followed by final runs with thicker rods, each run being well deslagged before the next is laid.

Vertical welding

All welds inclined at a greater angle than 45° to the horizontal can be classed as vertical welds.

Vertical welding may be performed either upwards or downwards, and in both methods a short arc should be held to enable surface tension to pull the drop across into the molten pool. Electrodes 4 mm diameter or smaller

Fig. 8.27. (*a*) A horizontal vertical fillet weld showing good penetration. (*b*) Showing poor penetration at corner of fillet



are generally used, and special rods having light coatings to reduce difficulties with slag are available. Vertical beads should first be run on mild steel plate, the electrode being held at 75–90° to the plate (**Fig. 8.28**).

Downward welding produces a concave bead, and is generally used for lighter runs, since a heavy deposit cannot be laid. If it is, the metal will not freeze immediately it is deposited on the plate, and will drop and run down the plate. This method is, therefore, usually only used as a finishing or washing run over an upward weld because of its neat appearance, or for thin sections.

Fig. 8.28

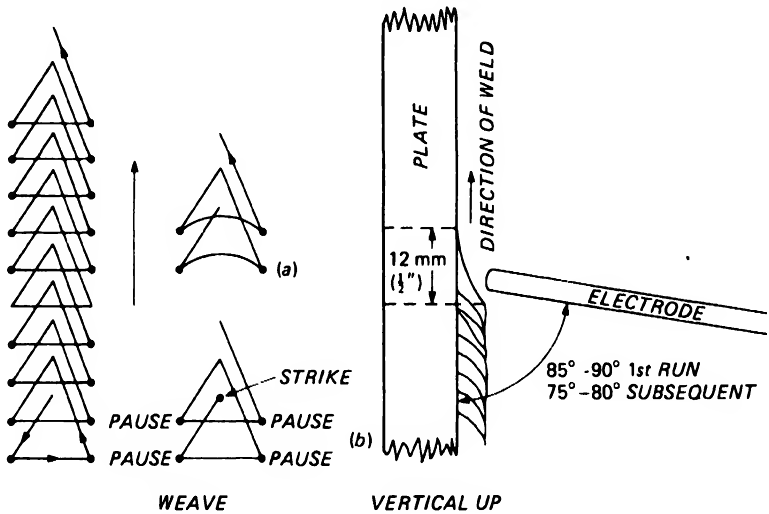
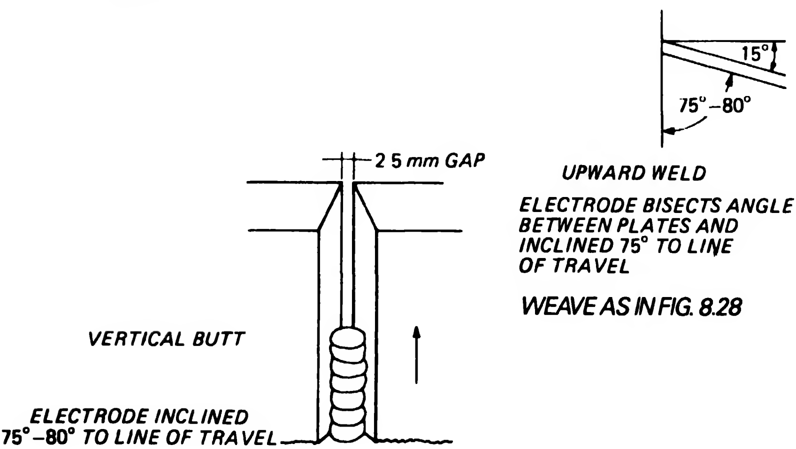


Fig. 8.29



Upward welding (**Fig. 8.29**) produces a convex bead, and is used on sections of about 6 mm thickness. The metal just deposited is used as a step on which to continue the deposit, and the slag flows away from the pool and does not hinder penetration as it does in the downward method.

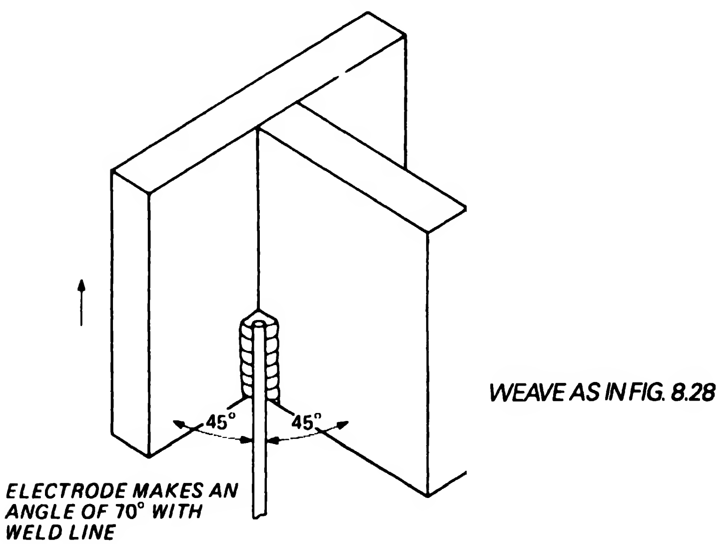
See **Fig. 8.28** for angle of electrode and method of weaving. Hesitate at each side and travel from left to right by moving upwards as shown. This keeps the upper side of the pool shallow and enables the slag to run away easily with no danger of entrapping. **Fig. 8.30** shows a vertical fillet weld.

Horizontal butt welding

This type of weld is very useful in fabrication, repair and reinforcement. A weaving motion is used for the first runs having prepared the plates as shown in **Fig. 8.31** with a medium current and a short arc. Subsequent runs can be made with very little weave and again a short arc – avoid undercutting the upper plate. (Note that there is little if any preparation of the lower plate.)

In reinforcement of vertical surfaces, the horizontal layer may be first laid along the bottom of the surface and succeeding beads built up above this, using the lower bead in each case as a step. The next layer is then deposited with the beads at right angles to those in the first layer as in padding, this second layer consisting of normal vertical beads. An alternative method is to lay all the beads vertically, though this is scarcely so satisfactory.

Fig. 8.30. Vertical fillet weld



Overhead welding

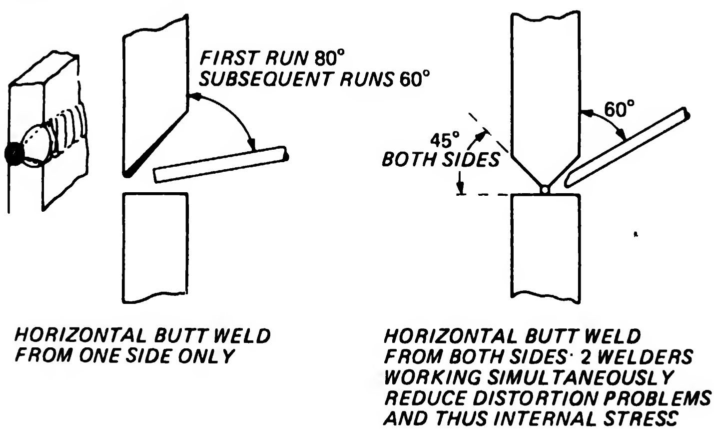
Overhead welding takes a great deal of practice before the operator can deposit an even weld with no blemishes. The weld should be made with electrodes of 3.2 or 4 mm diameter specially designed for all positional welding. The slag from these rods is fluid and does not give much trouble when welding. Because the electrodes are relatively small in diameter, overhead welding is a relatively slow process and should only be used when it is not possible to perform the welding in any other position such as downhand. An example is the overhead position when welding on the underside of a pipe joint in pipeline welding.

The operator must wear suitable protective clothes, tight wrist protection, gauntlet gloves, protective apron over shoulders and neck, no turn-ups on trouser bottoms and protective leather apron. The welding mask must completely cover face, head and neck. The welding position must be comfortable with the weight of the welding cable taken over the shoulder and the position should be such that molten slag (or even metal) does not fall on the operator.

Overhead butt weld **(Fig. 8.32*a*).** Using about 110 A for a 3.2 mm diameter rod make the first or root run with no weave and the rod at about 80–85° to the weld line. The arc must be as short as possible to enable surface tension and the magnetic forces to pull the metal up into the pool against the pull of gravity. After cleaning the first run, the subsequent runs are made with a little weave using a 4 mm diameter electrode and a current of about 160 A.

Overhead fillet welds are made with the same electrode and current settings as the overhead butt joint. Keep the arc very short and use no weave. If,

Fig. 8.31. Horizontal butt welds



because of the short arc, the electrode persists in sticking, raise the current a little, and avoid undercutting of the upper plate (**Fig. 8.32*b***).

Aluminium and aluminium alloys

Aluminium can be arc welded using electrodes coated with fluxes consisting of mixtures of fluorides and chlorides. The flux dissolves the layer of aluminium oxide (alumina) on the surface of the metal, and also prevents oxidation during welding. The melting point is about **660°C** but aluminium has a high thermal conductivity and as a result, since there is little if any change of colour before melting point is reached, as with steel, the rapid melting which occurs presents the operator with some difficulty when first beginning welding aluminium. Except for the thinnest sheets, pre-heating to the range 100–300°C should be carried out and great pains taken that the area of welding is free from all oxides, paints, and other contamination and the joint should be cleaned by wire brushing or machining immediately before beginning to weld.

Fig. 8.32. (*a*) Overhead butt weld with backing bar

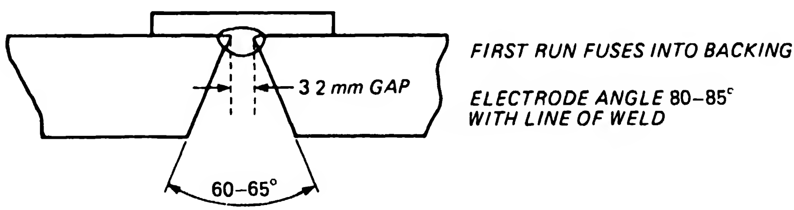
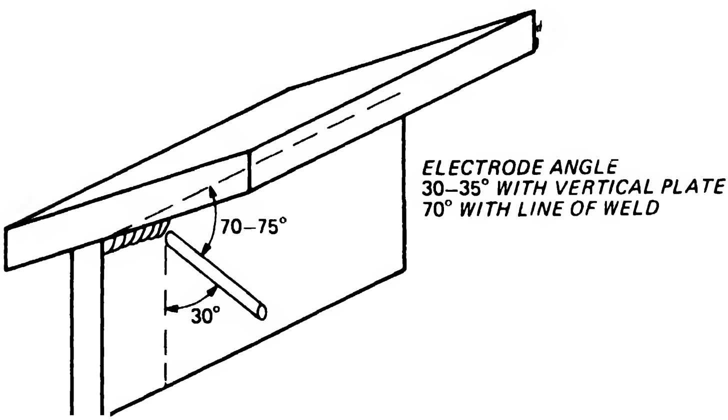


Fig. 8.32. (*b*) Overhead fillet weld



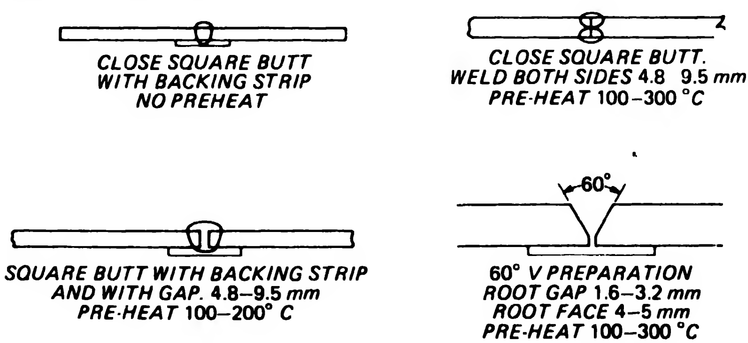
Preparation. Fig. 8.33 shows the preparation for various sheet thicknesses. Tack welds, jigs, or other clamps should be used to position the work and tack welding should be done at very frequent intervals, then deslagged and smoothed before welding commences. The thermal expansion is about twice that of mild steel so allowance must be made accordingly. Molten aluminium absorbs hydrogen and this results in porosity so that preheating the work and making sure that the electrodes are kept dry and heating to 130–160°C prevents this.

The table shows the more generally welded alloys. The electrodes used are of the 10–12% silicon type, so that if heat treatable alloys are welded the heat treatment is lost and the alloy needs heat treatment again. The Al–Si electrode does not have the same mechanical properties as the parent plate in every case, and it should be remembered that the higher Al-Mg alloys are not satisfactorily arc welded. Aluminium and the work hardening Al–Mg alloys are now fabricated by the TIG and MIG processes (q.v.).

Electrodes	*Material examples*
Aluminium–10% Si	Pure aluminium, 5251 (N4), 6063 (H9), 6061 (H20), 6082 (H30), Castings LM18, LM6, LM8, LM9, LM20.

Technique. The rod is connected to the positive pole of a d.c. supply, and the arc struck by scratching action, as explained for mild steel. It will be found that, as a layer of flux generally forms over the end of the rod, it has to be struck very hard to start the arc. The rod is held at right angles to the work and a *short* arc must be held (Fig. 8.34), keeping the end pushed down into the molten pool. This short arc, together with the shielding action of the coating of the rod, reduces oxidation to a minimum. A long arc will result in a weak, brittle weld. No weaving need be performed, and the rate of

Fig. 8.33. Preparation of aluminium.



welding must be uniform. As the metal warms up, the speed of welding must be increased.

Castings are welded in the same way after preparation, but owing to their larger mass, care must be taken to get good fusion right down into the parent metal, since if the arc is held for too short a time on a given portion of the weld the deposited aluminium is merely 'stuck' on the surface as a bead with no fusion. This is a very common fault. Castings should be pre-heated to 200°C to reduce the cracking tendency and to make welding easier.

Lap joints and fillet joints should be avoided since they tend to trap corrosive flux, where it cannot be removed by cleaning. Fillet welds are performed with no weave and with the rod bisecting the angle between the plates.

After treatment. The flux is very corrosive and the weld must be thoroughly washed and brushed in hot water after it has cooled out. Immersion in a 5% solution of nitric acid in water is an even better method of removing the flux, this being followed by brushing and washing in hot water.

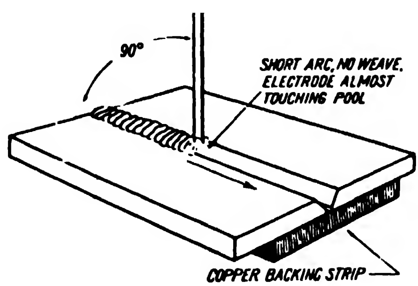
Cast iron

The following types of electrode are in general use for the welding of cast iron.

(1) Mild steel, low carbon, basic coated (low hydrogen), electrode d.c. + ve, a.c. 40 OCV.
(2) Nickel cored, electrode d.c. + ve, a.c. 40 OCV.
(3) MONEL* nickel–copper alloy* cored electrode, d.c. +ve, a.c. 40 OCV.†
(4) Nickel iron cored electrode, d.c. – ve, a.c. 40 OCV.

(1) When steel-based weld metal is deposited on cold cast iron, quick cooling results, due to the large mass of cold metal near the weld. This quick

Fig. 8.34. Aluminium welding



* MONEL, INCOLOY, INCONEL, etc. are trademarks of the Inco family of companies.
† See table, p. 413.

cooling results in much of the carbon in an area adjacent to the weld being retained in the combined form (cementite) and thus a hardened zone exists near the weld. In addition, the steel weld metal absorbs carbon and the quick cooling causes this to harden also. As a result welds made with this type of rod have hard zones and cannot always be machined.

If, however, there can be pre-heat to about 500–600 °C followed by slow cooling the deposit may produce machinable welds. In many cases, however, machining is not necessary, thus this drawback is no disadvantage. The weld is strong and electrodes of about 3.2 mm diameter are generally used with a low current which introduces a minimum of heat into the work.

(2) The nickel cored electrode may be used on cast iron without any pre-heating and it gives a deposit that is easily machinable with easy deslagging. It can be used in all positions and is used for buttering layers.

(3) The MONEL® alloy cored electrode is easy to deposit on cold cast iron and is again easily machinable. Nickel and MONEL® alloy electrodes have reduced carbon pick-up and thus a reduced hardening effect, but pre-heating should be done with castings of complicated shape, followed by slow cooling though, with care, even a complicated casting may be welded satisfactorily without pre-heat if the welding is performed slowly. The lower the heat input the less the hardening effect in the HAZ.

(4) Electrodes which deposit nickel–iron alloy are generally used where high strength is required, as for example with the SG irons.

In the repair of cast iron using high nickel electrodes the weld metal is strong and ductile. The electrode coating has a high carbon content and gives up to $1\frac{1}{2}\%$ carbon, as graphite, in the weld. The carbon has a low solubility in the nickel and excess carbon appears in the weld, increasing weld volume and reducing shrinkage. Pre-heating may be done whenever the casting is of complicated shape and liable to fracture easily, though, with care, even a complicated casting may be welded satisfactorily without pre-heating if the welding is done slowly.

Nickel alloy electrodes are also used for the welding of SG cast irons, but the heat input will affect the pearlitic and ferritic structures in the heat-affected zone, precipitating eutectic carbide and martensite in a narrow zone at the weld interface even with slow cooling. For increased strength, annealing or normalizing should be carried out after welding. The lower the heat input the less the hardening effect in the HAZ. **See table, p.413,** for suitable electrodes.

Preparation. Cracks in thin castings should be V'd or, better still, U'd, as for example with a bull-nosed chisel. Thicker castings should be prepared with

a single V below 9.5 mm thick and a double U above this. Studding (q.v.) can be recommended for thicker sections and the surrounding metal should be thoroughly cleaned. The polarity of the electrode depends on the electrode being used and the maker's instructions should be followed, though with d.c. it is generally + ve. With a.c. an OCV of 80 V is required.

Since the heat in the work must be kept to a minimum, a small-gauge electrode, with the lowest current setting that will give sufficient penetration, should be used. A 3.2 mm rod with 70 to 90 A is very suitable for many classes of work. Thick rods with correspondingly heavier currents may be used, but are only advisable in cases where there is no danger of cracking. Full considerations of the effect of expansion and contraction must be given to each particular job.

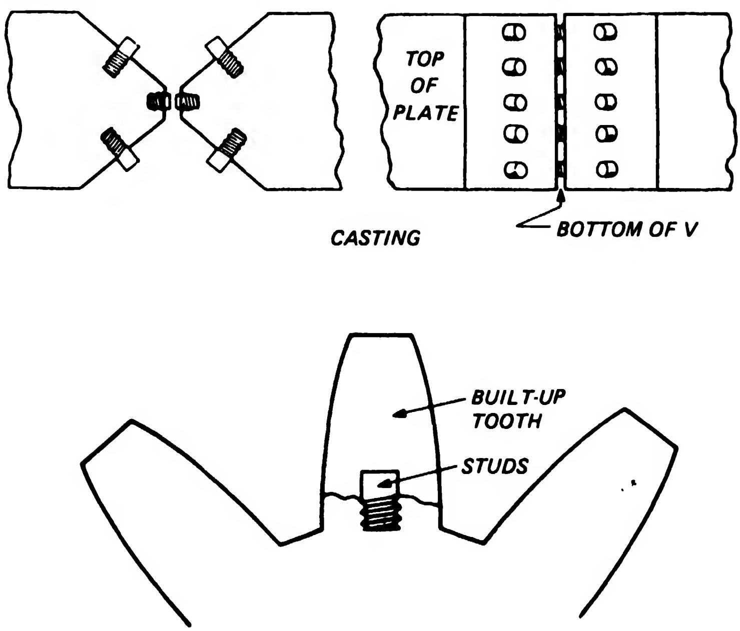
Technique. The rod is held as for mild steel, and a slight weave can be used as required. Short beads of about 50 to 60 mm should be run. If longer beads are deposited, cracking will occur unless the casting is of the simplest shape. In the case of a long weld the welding can be done by the skip method, since this will reduce the period of waiting for the section welded to cool. It may be found that with steel base rods, welding fairly thin sections, fine cracks often appear down the centre of the weld on cooling. This can often be prevented, and the weld greatly improved, by peening the weld immediately after depositing a run with quick light blows with a ball-paned hammer. If cracks do appear a further light 'stitching' run will seal them. Remember that the cooler the casting is kept, the less will be the risk of cracking, and the better the result. Therefore take time and let each bead cool before laying another. The weld should be cool enough for the hand to be held on it before proceeding with the next bead. In welding a deep V, lay a deposit on the sides of the V first and follow up by filling in the centre of the V. This reduces risk of cracking. If the weld has been prepared by studding (q.v.), take care that the studs are fused well into the parent metal.

In depositing non-ferrous rods, the welding is performed in the same way, holding a short arc and welding *slowly*. Too fast a welding speed results in porosity. In many cases a nickel- copper rod may be deposited first on the cast iron and then a steel base rod used to complete the weld. The nickel copper rod deposit prevents the absorption of carbon into the weld metal and makes the resulting weld softer. Where a soft deposit is required on the surface of the weld for machining purposes, the weld may be made in the ordinary way with a steel base rod and the final top runs with a non-ferrous rod. The steel base rod often gives a weld which has hard spots in it that can only be ground down, hence this weld can never be completely guaranteed machinable.

Studding

We have seen that whenever either steel base or non-ferrous rods are used for cast iron welding, there is a brittle zone near the line of fusion, and since contraction stresses are set up, a weakness exists along this line. This weakened area can be greatly strengthened in thick section castings by studding. Welds made by this method have proved to be exceptionally strong and durable. Studding consists of preparing the casting for welding with the usual single or double V, and then drilling and tapping holes along the V and screwing steel studs into the holes to a depth slightly deeper than the diameter of the studs. Studs of 4.8 mm diameter and larger are generally used, depending on the thickness of the casting, and they must project about 6 mm above the surface. The number of studs can be such that their area is about $\frac{1}{5}$ to $\frac{1}{4}$ of the area of the weld, though a lesser number can be used in many cases **(Fig. 8.35)**. Welding is performed around the area near each stud, using steel or steel base electrodes, so as to ensure good fusion between the stud and the parent casting. These areas are then welded together with intermittent beads, as before explained, always doing a little at a time and keeping the casting as cool as possible. This method should always be adopted for the repair, by arc welding, of large castings subjected

Fig. 8.35. Methods of studding



to severe stress. An alternative method is to weld steel bars across the projecting studs as additional reinforcement.

Copper, bronze and brass welding

If the weld must have the same characteristics as the parent metal, as for example for electrical conductivity, great difficulty is encountered with the welding of copper by the MMA process because the weld is very porous and unsatisfactory and the TIG and MIG processes should be chosen. Similarly for brass but with the use of an alloy electrode of bronze (about 80% copper, 20% tin or similar) welding can be satisfactorily carried out on most of the copper alloys with certain exceptions. Welding is performed with d.c. and the electrode positive.

Copper, copper–tin (bronze) and copper–zinc (brass) have a much greater coefficient of thermal conductivity than mild steel and the thermal expansion is also greater so that more heat is required in the welding process, so that it is almost imperative to pre-heat except with the smallest sections, and since tack welds lose their strength at elevated temperatures, line up of the parts to be welded should be with clamps, jigs or fixtures, and due allowance made for expansion and contraction during and after welding. In general, great care must be taken to avoid porosity due to the presence of gas which is expelled on solidification. Stress relief (post weld) can be carried out on the work hardening alloys to about 250–300°C.

Copper. Tough pitch copper should not be welded as the weld is always porous. Phosphorus deoxidized copper is satisfactorily welded but the weld, made with a rod of copper–tin (bronze) will not have the same properties as the parent plate. Pre-heating is up to 250°C.

Bronze. The tin bronzes up to about 9% Sn are weldable, but those with higher tin content are not welded due to solidification cracking and any alloy with more than 0.5% Pb is usually not welded.

Brasses. These are alloyed mostly with zinc and those with single-phase composition, as for example cartridge brass (70% Cu, 30% Zn) and those with up to about 37% Zn, are weldable, but yellow or Muntz metal (60% Cu, 40% Zn) and manganese bronze (58% Cu, 38% Zn, rem. Mn, Fe, Ni or Sn) really need pre-heat to about 450°C.

Preparation. Plates below 3 mm thickness need no preparation, but above this they are prepared as for mild steel with a 60° V and the surfaces thoroughly cleaned. The work must be supported during welding. Sections

above about 4 mm must be pre-heated to 250 °C because of the high thermal conductivity of the metal.

Technique. The rod should be connected to the +ve pole of a d.c. supply except where otherwise stated. The current value is generally the same as or slightly less than that for the same gauge mild-steel electrode, with an arc voltage drop of 20–25 V. The actual values will depend on the particular job. The electrode should be held steeply to the line of weld, and a short arc held keeping the electrode well down into the molten pool. The weld must be made *slowly*, since a quick rate of welding will produce a porous deposit even when bronze rods are used. As welding proceeds and the part heats up, it is usually advisable to reduce the current, or there is a liability to melt through the weld, especially in thinner sections. Light hammering, while still hot, greatly improves the structure and strength of the weld. The extent to which this should be done depends on the thickness of the metal.

Hard surfacing

Surface resistance to abrasion, impact, corrosion and heat. The advantages of hard surfacing are that the surfaces can be deposited on relatively much cheaper base metal to give the wear-resistant or other qualities exactly where required, with a great saving in cost. In addition built-up parts save time and replacement costs. The chief causes of wear in machine parts are abrasion, impact, corrosion and heat. In order to resist impact the surface must be sufficiently hard to resist deformation yet not hard enough to allow cracks to develop. On the other hand, to resist abrasion a surface must be very hard and if subject to severe impact conditions cracking may occur, so that in general the higher the abrasion resistance the less the impact resistance, and evidently it is not possible to obtain a surface which has the highest values of both impact and abrasion resistance. In choosing an electrode for building up surfaces consideration must be given as to whether high abrasion or high impact resistance is required. High-impact electrodes will give moderate abrasion resistance and vice versa, so that the final choice must be made as to the degree of (1) hardness, (2) toughness, (3) corrosion resistance, (4) temperature of working, (5) type of base metal and whether pre- and post-heating is possible. The main types of wear- and abrasion-resistant surfacing electrodes are:

(1) Fused granules of tungsten carbide in an austenitic matrix. The deposit has highest resistance to wear but is brittle and has medium impact strength. The electrodes are tubular and therefore moisture-resistant with high deposition rates.

(2) Chromium carbide. The basic-coated electrodes deposit a dense network of chromium carbide in an austenitic matrix and have high resistance to wear with good impact resistance.
(3) Cobalt–chromium–tungsten non-ferrous alloys. These have a high carbon content, are corrosion-resistant, have a low coefficient of friction and retain their hardness at red heat.
(4) Nickel-base alloys containing chromium, molybdenum, iron and tungsten. These have good abrasion resistance and metal-to-metal impact resistance. They work-harden and have resistance to high-temperature wear and corrosive conditions.
(5) Air-hardening martensitic steels. These have a high hardness value due to their martensitic structure and there is a variety of electrodes available in this group. Dilution plays an important part in the hardness of the deposit, as with all surfacing applications. A single run on mild steel may be only a little harder than the parent plate, but if deposited on carbon or alloy steel, carbon and alloy pick-up greatly increases the hardness of the deposit.
(6) Austenitic steels: (1) 12/14% manganese deposits develop their hardness by cold work-hardening so that the deposit has the strength of its austenitic core with the hard surface. With approximately 3% Ni there is reduced tendency to cracking and brittleness due to heat compared with plain 12/14% Mn weld metal. (2) Chromium–nickel, chromium–molybdenum–nickel and chromium-manganese deposits work-harden and give resistance to heavy impact.

Thus, in general, low-alloy deposits give medium abrasion with high impact resistance, medium-alloy deposits give high abrasion and medium impact properties.

Austenitic, including 13% manganese, deposits give high impact resistance and work-harden as a result of this impact and work to give abrasion-resistant qualities. Of the carbides, chromium deposits give the best abrasion and impact properties while tungsten has the hardest surface and thus the highest resistance to abrasion with medium impact properties.

The table overleaf gives a selection of electrodes available.

Preparation and technique

The surface should be ground all over and loose or frittered metal removed. Because of the danger of cracking, large areas should be divided up and the welding done in skipped sections so that the heat is distributed as evenly as possible over the whole area. Sharp corners should be rounded and thick deposits should be avoided as they tend to splinter or spall. The

Type (R – rutile) (B – basic) (T – tubular)		Hardening	HV	Use	Abrasion (H – high) (M – medium)	Impact
pearlitic P	Cr–Mn	air	250	Used also for butter layers.	M	M
martensitic R	Cr–Mn	air	350	For and with buffer layers.	M	H
martensitic R	Cr–Mn–Mo	air	650	After buffer layers.	H	M
martensitic B	Cr–Mo–V	air	700	After buffer layers for heavy reinforcement.	H	M
martensitic B	Cr–Mo with borides	air	800	Surfacing generally restricted to two layers.	H	M
austenitic B	Cr–Mo–Ni	work	250 500	For joining and depositing on 13% Mn steel and joining this steel to carbon steel.	M	M
austenitic B	Cr–Ni–W–B	work (slight)	450 500	Hard at elevated temperatures, corrosion-resistant.	M	M
austenitic B	13% Mn	work	170 500		H	M
austenitic T	Cr–Mn	work	300 480	For reinforcing 13% Mn steel castings and as buffer layer for harder surfaces.	M	H
non-ferrous B	Co–Cr–W		630	Red hard and corrosion-resistant, various grades.	H	M
austenitic T matrix	Chromium–carbide–Mn		560 matrix 1400 carbides	Heat resistant to about 1100 C.	H	H
non-ferrous T matrix	tungsten–carbide		600 matrix 1800 carbides	Used at all temperatures.	H	M

first runs on any surface are subject to considerable dilution, so it is advisable to lay down a buffer layer using a nickel-based or austenitic stainless steel electrode, especially when welding on high carbon or high alloy steels. The buffer layer should be chosen so as to be of intermediate hardness between the parent metal and the deposit, or two layers should be used with increasing hardness if the parent metal is very soft compared with the deposit.

Mild pre-heating to 150–200 °C is advantageous if the base metal has sufficient carbon or alloying elements to make it hardenable but is not usual on steel below 0.3% C or stainless steel. If the base metal is very hard and brittle, slow pre-heating to 400–600 °C with slow cooling after welding may be necessary to prevent the formation of brittle areas in the HAZ. Below a hardness value of 350 HV (hardness Vickers), surfaces are machinable generally with carbide tools but above this grinding is usually necessary. In depositing a surface on manganese steel there should be no pre-heating or stress relieving and the electrode should be connected to the + ve pole. Use only sufficient current to ensure fusion, keep a short arc, hold the electrode as in welding mild steel and introduce as little heat as possible into the casting by staggering welding so that the temperature does not rise much above 200 °C. Austenitic stainless steel electrodes should be used for joining broken sections as these electrodes work-harden in the same way as the parent metal and 13% manganese, or 13% manganese, 3.5% nickel electrodes used for building up.

Dilution is about 25–35% in the first layer, and to obtain a dilution of about 5% at least three layers must be laid down with a thickness of 6–10 mm.

Note. The manual metal arc method of surfacing is rather slow compared with semi-automatic and automatic processes such as MIG and submerged arc so that it is best suited for smaller areas and complex shapes.

Corrosion-resistant surfacing

Nickel and its alloys can be laid as surfaces on low carbon and other other steel to give corrosion- and heat-resistant surfaces. Electrode diameter should be as large as possible, with minimum current compatible with good fusion to reduce dilution effects. The first bead is laid down at slow speed and subsequent runs overlapped with minimum weaving, reducing dilution to 15–20% compared with 25–35% for the first bead. Subsequent layers should be put down with interpass temperature below 180 °C to minimize dilution and avoid micro-fissures in the deposit. Dilution is reduced to about 5% after three layers with 6–10 mm thickness. Suitable electrodes are in the Nickel, MONEL®, INCONEL®, INCOLOY® and INCO® alloy ranges, for which the student should refer to manufacturers' instructions.

Tipping tool steel

Cutting tools for lathes, milling machines and high-speed cutting tools of all types can be made by depositing a layer of high-speed steel on to a shank of lower carbon steel. Special electrodes are made for this purpose, and give very good results.

The surface to be tipped is ground so as to receive the deposit. The electrode is connected to the + ve pole when d.c. is used, and held vertically to the line of weld, a narrow deposit being laid as a general rule. More than one layer is generally advisable, since the first layer tends to become alloyed with the parent metal For this reason the current setting should be as low as possible, giving small penetration. Use a very narrow weave so as to prevent porosity, which is very usual unless great care is taken. Each bead should be allowed to cool out and then be deslagged before depositing the next. The deposited metal when allowed to cool out slowly usually has a Brinell hardness of 500–700, depending upon the rod used. The hardness can be increased by heat treatment in the same way as for high-speed tool steel, and the deposit retains its hardness at fairly high temperatures.

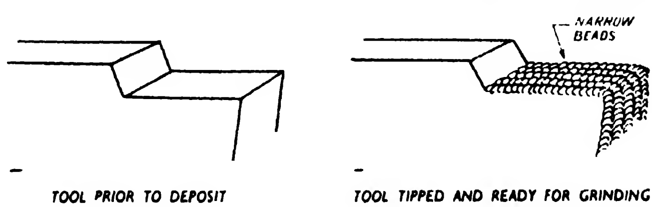
These types of rods are very suitable for depositing cutting edges on drills, chisels, shearing blades, dies and tappets, etc Fig. 8.36 shows the method of depositing the surface on a lathe tool

Stellite (Cobalt base and nickel base alloys for hard surfacing)

Stellite is an alloy of cobalt, chromium, tungsten and carbon, and when deposited on steel, steel alloy or cast iron it gives a surface having excellent wear-resisting qualities and one that will stand up well to corrosive action. It preserves its hardness of surface even when red-hot (650°C), and is thus suitable for use in places where heat is likely to be generated.

It may be deposited very satisfactorily with the arc, though the deposit is not as smooth as one deposited with the oxy-acetylene flame. The arc method of application, however, is specially recommended where it is essential not to introduce undue heat into the part, due to danger of warping or cracking In many cases, especially where the part has large mass, Stelliting by the arc saves time and money compared with the flame. Bare rods of stellite may be used when welding with d.c. and are connected to the + ve pole If a c. is employed, covered rods must be used; and better

Fig. 8.36



results are also obtained with covered rods when using d.c., since the deposit is closer grained and the arc more stable.

Covered rods can be obtained or bare rods may be fluxed with a covering of equal parts of calcium carbonate (chalk), silica flour and either borax or sodium carbonate (baking soda), mixed with shellac as a binder. Coated electrodes give a gas shield which protects the molten metal from oxidation in the welding process and provides a protective slag over the metal when cooling. The deposit resists heat, abrasion, impact, corrosion, galling, oxidation, thermal shock and cavitation erosion to varying degrees depending upon the alloy. Types of Stellite alloys available are:

No. 1. 2.5% C, resistant to abrasion and solid particle erosion, slightly reduces toughness. Used for screw components and pump sleeves. 46 C (Rockwell).

No. 6. Most generally useful cobalt alloy, 1% C, 28% Cr, 4% W, rem. Co. Excellent resistance to mechanical and chemical action over a wide temperature range. Widely used as valve seat material as it has high temperature hardness and high resistance to cavity erosion.

No. 12. Very similar to alloy No. 6 but with higher hardness. Used for cutting edge in carpet, plastics, paper and chemical industries. 40 C.

No. 21. Low carbon, Co–Cr alloy with molybdenum. Has high temperature strength, resistant to cavitation erosion, corrosion and galling. Used for hot die material, fluid valve seat facing.

No. 238. Co–Fe Cr Mo alloy, low carbon. Has excellent resistance to mechanical and thermal shock with good hot hardness.

No. 2006. Low cobalt alternative to No. 6 to which it is similar in galling and cavitation erosion properties, but has better abrasive wear and metal-to-metal sliding conditions. Used for hot working dies and shears.

No. 2012. Low cobalt alternative to No. 12. Has improved resistance to abrasion but is not as tough. Can be used for cutting edges.

It should be noted that in some cases the nickel-based alloys, such as C 0.15%, Cr 17%, Mo 17%, Fe. 6%, Rem. Ni, available in covered electrode form may be superior to the cobalt-base alloys.

See also the section on hard surfacing in Chapter 13.

Preparation. The surface to be Stellited must be thoroughly cleaned of all rust and scale and all sharp corners removed. A portable grinder is extremely useful for this purpose. In some cases, where the shape is complicated, pre-heating to prevent cracking is definitely an advantage. A slightly longer arc than usual is held, with the rod nearly perpendicular to the surface, as this helps to spread the Stellite more evenly. Care must be

taken not to get the penetration too deep, otherwise the Stellite will become alloyed with the base metal and a poor deposit will result. Since Stellite has no ductility, cooling must be at an even rate throughout to avoid danger of cracking. The surface is finally ground to shape. Lathe centres, valve seats, rock drills and tool tips, cams, bucket lips, dies, punches, shear knives, valve tappet surfaces, thrust washers, stillson teeth, etc., are a few examples of the many applications of hard surfacing by this method.

Stainless steels

Note on BS 2926. This standard includes the chromium-nickel austenitic steels and chromium steels and uses a code by which weld metal content and coating can be identified.

The first figure is the % chromium content, the second figure the % nickel content and the third figure the % molybdenum content. The letter L indicates the low carbon version, Nb indicates stabilization with niobium, W indicates that there is tungsten present. R indicates a rutile coating, usually either d.c. or a.c., and B a basic coating, usually d.c. electrode + ve only. A suffix MP indicates a mild steel core.

For example: 19.12.3.Nb.R is a nobium-stabilized 19% Cr, 12% Ni, 3% Mo, rutile-coated electrode.

Stainless steel welding

Martensitic (chromium) stainless steels. These steels contain 12–16% chromium and harden when welded. The carbon content is usually up to 0.3% but may be more. They are used for cutlery and sharp-edged tools and for circumstances in which anti-corrosion properties are important. They harden when welded so that they should be pre-heated to 200–300°C and then allowed to cool slowly. After welding they should then be post-heated to about 700°C to remove brittleness. By using an austenitic electrode of the 25.12.Cr.Ni type with 3% tungsten (see table, pp. 408-9) the weld is more ductile and freer from cracking. If, however, the weld must match the parent plate as nearly as possible, electrodes of the chromium type must be chosen but are not very satisfactory. Use the austenitic rod where possible.

Ferritic stainless steel. Ferritic steels contain 16–30% Cr, do not harden when welded but suffer from grain growth when heated in the 950–1100°C range, so that they are brittle at ordinary temperatures but may be tougher at red heat. Pre-heating to 200°C should be carried out and the weld completed, followed by post-heating to 750°C. For mildly corrosive conditions, electrodes of matching or higher chromium content should be used, e.g. 25.12.3.W, which give a tough deposit. If joint metal properties need not match the parent plate, electrodes of 26.20 can be used. It should be noted that the weld deposit of these electrodes contains nickel which is

attacked by sulphurous atmosphere, so they are only suitable for mildly corrosive conditions.

Austenitic stainless steels. These largely non-magnetic steels form the largest and most important group from the fabrication point of view. They do not harden when welded because of their austenitic structure, the largest group being the 18% Cr 8% Ni type with other groups such as 25% Cr 20% Ni and 18% Cr 12% Ni. Other elements such as molybdenum are added to make them more acid-resistant, and they are available with rutile coatings suitable for d.c. electrode +ve or a.c. minimum OCV 55–80 V depending upon the electrode; or with basic coatings usually for d.c. only, electrode +ve, these being especially suitable for vertical and overhead positions. The table gives a selection of electrodes available.

Technique. These steels have a greater coefficient of expansion than mild steel so that the tendency to distort is greater. Tack welds should be placed at about twice the frequency as for mild steel but clamps and jigs are very suitable. The technique is similar to mild steel but the arc should be struck on a striking plate and avoid any stray arcing. Welding should be done with a short arc to avoid loss of alloying metals in the transference over the arc gap. Keep the electrode at about 80° to the line of travel using as low a current as possible to ensure penetration, since the lower conductivity of stainless steel reduces the width of the HAZ and excess current will cause burn through. After welding, clean with a brush having stainless steel wires – grinding is also satisfactory. Weaving should be about twice rod width and watch for any crack down the centre line of the weld indicating hot cracking due to restraint (see table on p. 408).

Duplex stainless steels*. These are austenitic/ferritic steels having 35–75% ferrite, 22–25½% Cr, 5–6½% Ni and 3% Mo. They are used in the petrochemical industry for both plant and pipe-lines. They can be welded using electrodes specially designed for the purpose (such as Nirex DPC®), containing 22% Cr, 9% Ni and 3% Mo. The coating is generally of acid-rutile type, requiring no pre- or post-heat. Since these steels are not used in conditions above 300 °C, the interpass temperature must not exceed 200 °C. Nitric acid grade resistant steel, NAG (no. 329) is extremely resistant to nitric acid. Precipitation-hardening steels (e.g. FV520) are fully austenitic or martensitic. The latter type should be age-hardened after welding, but some austenitic types are unweldable due to hot cracking. Follow the manufacturer's instructions.

Most stainless steels can be welded by MMA (MMAW), MIG, GMAW, TIG (GTAW) as well as by laser and electron beam processes, the wire rod being matched to the parent plate.

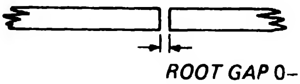
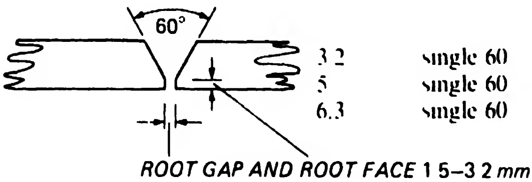
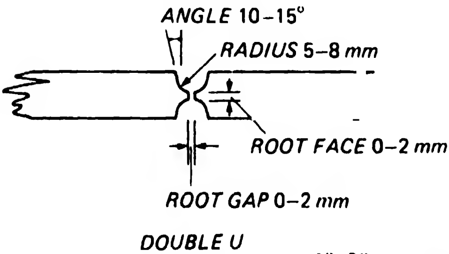
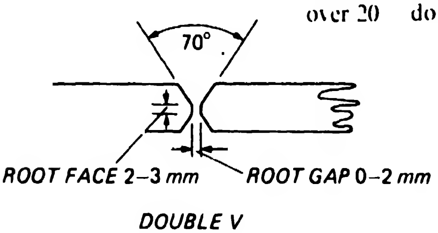
* See also Appendix 15.

Examples of electrodes for stainless and heat resistant steels

Electrode a.c. OCV	d.c.	British Standard 2926 Cr	Ni	Mo		A.W.S. equivalent	Coating	UTS (N/mm^2)	Applications
80	+	19	9	–	Nb	E347–16	R	650	For the welding of plain or stabilized stainless steels.
60	+	19	12	3	L	E316L–16	R	610	For welding Mo bearing stainless steels of 316 or 316L type.
60	+	19	9	–	L	E308–16	R	610	For 18/8 Cr–Ni steels with low carbon deposit (0.03).
100	+	25	20	–		E310–15	B	640	For heat- and corrosion-resistant stainless steels of similar composition. Also low alloy and mild steel to stainless steel with low restraint – non-magnetic.
85	+	19	9	–		E308–16L	R	585	For unstabilized stainless steel of this composition. Also for welding and surfacing 14% Mn steels.
65	+	19	9	–	Nb	E347–16	R	650	Austenitic electrode for Nb stabilized stainless steels of the 19/9 class. Can be used all positional.
70	+	19	12	3	Nb	E316–16	R	640	Austenitic electrode for unstabilized stainless steels and similar types.

55	+	19	12	3	Nb	E318-16	R		For all plain or Ti or Nb stabilized stainless steels.
—	+	19	12	3	Nb	E318-15	B	640	Austenitic electrode for Ti or Nb stabilized stainless steels. Suitable for vertical and overhead welding, e.g. fixed pipe work, d.c. only.
60	+	19	13	4	L	E317	R	630	For AISI 317 steels. Carbon below 0.08%.
85	+	17	8	2		E16-8-2	B	630	Ferrite controlled with 2% Mn. Suitable for all similar types especially for long service at elevated temperatures, e.g. in steam pipes and gas turbines.
—	+	23	12	-		E309-15	B	587	Deposits of 22/12 Cr-Ni for welding clad steels of Cr-Ni of similar composition and for dissimilar metals.
55	+	23	12	2		E309-Mo-16	R	569	For clad steels with a deposit of AISI 309Mo type, also for dissimilar metals and stainless steel to mild steel.
70	+	29	10	-		E312-16	R	800	For dissimilar steels, nickel steels, hardenable steels or steel of the same composition. Ferrite about 35%.

Stainless steel butt weld preparation

	Plate thickness (mm)	Preparation	Suggested electrode diameter (mm)
	1.2–1.6 2.0 2.5	square edge square edge square edge	1.6 2.0 2.5
	3.2 5 6.3	single 60 single 60 single 60	2.5 3.2 3.2 and 4
 	10–20 over 20	single 60 or double 70 double 70 or double U	4 and 5 4 and 5

Shaeffler constitutional diagram for stainless steel weld metal (Fig. 8.37)

The various alloying elements in a stainless steel are expressed in terms of (1) nickel, which tends to form austenite, and (2) chromium, which tends to form ferrite. Thus

Nickel equivalent $= \%\,Ni + (30 \times \%\,C) + (0.5 \times \%\,Mn)$

and

Chromium equivalent $= \%\,Cr + (\%\,Mo) + (1.5 \times \%\,Si) + (0.5$ Nb or Cb).

From the lines on the diagram we see that the low-alloy steels are hardenable because they contain the martensitic phase as welded. With increasing alloying elements, austenite and ferrite phases become more stable and the steel is no longer quench hardenable. Thus steels with high nickel, manganese and carbon become austenitic (shown in diagram) while those with high chromium and molybdenum are more ferritic (also shown). In the area $A + F$ the weld will contain both austenite and ferrite (duplex phase) and it can be seen how this leads to the designation of stainless steels as austenitic, martensitic and ferritic.

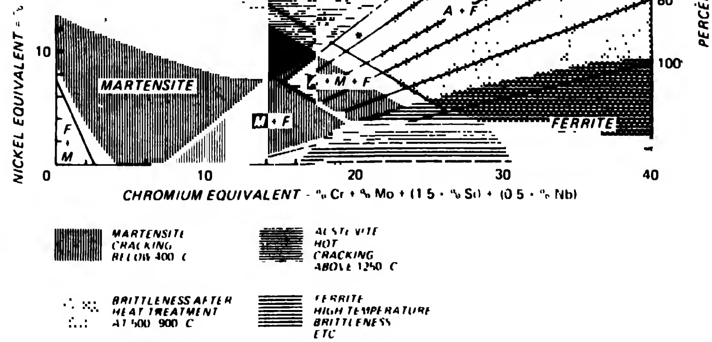
The shaded areas on the Shaeffler diagram indicate regions in which defects may under certain circumstances appear in stainless steel welds.

Example

Stainless steel BS 2926. 19.9.L.R. AWS equivalent E.308 L. Carbon 0.03 %, manganese 0.7 %, silicon 0.8 %, chromium 19.0 %, nickel 10.0 %.

$$\begin{aligned}
\text{Nickel equivalent} &= \%\ \text{Ni} + (30 \times \%\ \text{C}) + (0.5 \times \%\ \text{Mn}).\\
&= 10 + (30 \times 0.03) + (0.5 \times 0.7)\\
&= 10 + 0.9 + 0.35\\
&= 11.25.\\
\text{Chromium equivalent} &= \%\ \text{Cr} + \%\ \text{Mo} + (1.5 \times \%\ \text{Si}) + (0.5 \times \%\ \text{Nb})\\
&= 19 + 0 + (1.5 \times 0.8) + (0.5 \times 0)\\
&= 19 + 0 + 1.2 + 0\\
&= 20.2
\end{aligned}$$

Fig. 8.37. Constitution diagram for stainless steel welds (after Schaeffler) with approximate regions of defects and phase balance, depending on composition



By plotting the two values on the diagram we get the point marked * in the clear part of the diagram, giving the main phases present and giving some indication of how it will behave during welding.

The welding of stainless steel to low alloy steel* and mild steel

The technique for welding is similar to that for stainless steel but dilution is the greatest problem with this work. If the electrode used is a mild or low alloy steel, the weld will have a low nickel and chromium enrichment and will be subject to cracking problems. Because of this the joint between the steels should be welded with an austenitic stainless steel electrode of much higher chromium–nickel content, say 25–12 or 23–12–2 or 29–10, which will result in weld metal which will have up to 18% Cr and 8% Ni after allowing for dilution. This now has a high resistance to hot cracking but the 25–20 type electrode must not be subject to high weld restraint. See p. 93, for composition of core wire and coverings for steel electrodes.

Nickel and nickel alloys

The welding of nickel and its alloys is widely practised using similar techniques to those used for ferrous metals. The electrodes should be dried before use by heating to 120°C or, if they are really damp, by heating for 1–2 hours at about 260°C. Direct current from generator or rectifier with electrode positive gives the best results. A short arc should be held with the electrode making an angle of 20–30° to the vertical and when the arc is broken it should first be reduced in length as much as possible and held almost stationary, or the arc can be moved backwards over the weld already laid and gradually lengthened to break it. This reduces the crater effect and reduces the tendency to oxidation. The arc should be restruck by striking at the end of a run and moving quickly back over the crater, afterwards moving forward with a slight weave over the crater area, thus eliminating starting porosity.

Fig. 10.28 shows the most satisfactory joint preparation and it should be remembered that the molten metal of the nickel alloys is not as fluid as that of steel so that a wider V preparation is required with a smaller root face to obtain satisfactory penetration.

Each run of a multi-run weld should be deslagged by chipping and wire-brushed. Grinding should not be undertaken as it may lead to particles of slag being driven into the weld surface with consequent loss of corrosion resistance. Stray arcing should be avoided and minimum weaving performed because it results in poorer quality of weld deposit due to increased dilution.

* British and American classifications for low alloy steel electrodes are given on pp. 425–31.

Although it is preferable to make welds in the flat position, vertical welds can be made either upwards or downwards holding the electrode at right angles to the line of weld, using reduced current compared with similar flat conditions.

For fillet welds the electrode angle should roughly bisect the angle between the plates and be at right angles to the line of weld. If the plates are of unequal thickness the arc should be held more on to the thicker plate to obtain better fusion, and tilted fillets give equal leg length more easily.

The table gives a list of the alloys suitable for welding by this process and the type of electrode recommended.

Steels containing 9% nickel used for low temperature (−196°C) are welded with basic-coated electrodes using d.c., such as 80/20 nickel/chromium or INCO-WELD B® alloy electrodes. See table.

Material	Recommended covered MMA electrodes
Nickel and nickel alloys 200, 201	Nickel alloy 141
MONEL® alloy 400	MONEL® alloy 190
MONEL® alloy K500	MONEL® alloy 190
Copper–nickel alloys	MONEL® alloy 187
INCONEL® alloy 600	INCONEL® alloy 182, INCO-WELD® alloys A, B
INCONEL® alloy 601	INCONEL® alloys 182, 112, INCO-WELD® alloy A
INCONEL® alloy 625	INCONEL® alloy 112
INCONEL® alloy 617	INCONEL® alloy 117
INCONEL® alloy 690	INCO-WELD® alloy A, INCONEL alloy 112
INCO® alloy C276	INCO® alloy C276
INCO® alloy HX	INCO® alloy HX, INCONEL® alloy 117
INCO® alloy G3	INCONEL® alloy 112
INCOLOY® alloys 800, 800H, 800HT	INCO-WELD® alloys A, B, INCONEL® alloys 112, 117
INCOLOY® alloy 825	INCOLOY® alloy 135
INCOLOY® alloy DS	INCO-WELD® alloys A, B
NIMONIC® alloy 75	INCONEL® alloys 182, 112, INCO-WELD® alloys A, B
BRIGHT® alloy series	INCO-WELD® alloys A, B
NILO® alloy series	Nickel alloy 141, INCO-WELD® alloys A, B
Cast irons	NI-ROD® 44, 55X, 99X
Mo bearing steels	INCONEL® alloy 112

INCO-WELD® alloy A electrode is suitable for welding (cryogenic) 9% nickel steels.

Clad steels

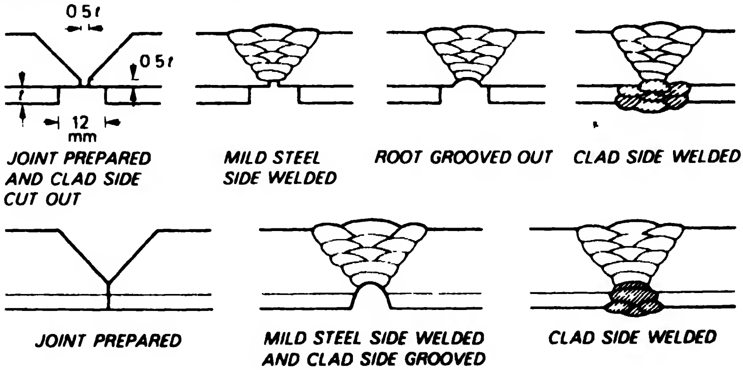
Stainless clad steel is a mild or low alloy steel backing faced with stainless steel such as 18% Cr 8% Ni or 18% Cr 10% Ni with or without Mo, Ti and Nb, or a martensitic 13% Cr steel, the thickness of the cladding being 10–20% of the total plate thickness.

Preparation and technique. The backing should be welded first and the mild steel root run should not come into contact with the cladding, so that preparation should be either with V preparation close butted with a deep root face, or the cladding should be cut away from the joint at the root (see Fig. 8.38). The clad side is then back grooved and the stainless side welded with an electrode of similar composition. Generally an austenitic stainless steel electrode of the 25% Cr 20% Ni type should be used for the root run on the clad side because of dilution effects, and at least two layers or more if possible should be laid on the clad side to prevent dilution effects affecting the corrosion-resistant properties. First runs should be made with low current values to reduce dilution effects. For martensitic 13% Cr cladding, pre-heating to 240 °C is advisable followed by post-heating and using an austenitic stainless steel electrode such as 22% Cr 12% Ni 3% Mo with about 15% ferrite, which gives weld metal of approximately 18% Cr 8% Ni with about 6% ferrite. Welding beads not adjacent to the backing plate can be made with 18% Cr 12% Ni 3% Mo electrodes. If the heat input is kept as low as possible welding may be carried out without heat treatment, the HAZ being tempered by the heat from successive runs.

Nickel clad steel

Mild and low alloy steel can be clad with Nickel, MONEL® or INCONEL® alloys for corrosion resistance at lower cost compared to solid nickel base material and with an increase in thermal conductivity and greater strength, the thickness of cladding usually being not greater than 6 mm. When welding clad steels it is essential to ensure the continuity of

Fig. 8.38. Alternative methods of welding clad steel



the cladding, and because of this butt joints are favoured. Dilution of the weld metal with iron occurs when welding the clad side, but the electrode alloy can accept this. First runs should be made with low current values to reduce the dilution.

Preparation of joints is similar to that for stainless clad steel. Recommended electrodes are given in the table on p. 413.

Welding of pipelines

The following brief account will indicate to the welder the chief methods used in the welding of pipelines for gas, oil, water, etc. The lengths of pipes to be welded are placed on rollers, so that they can easily be rotated. The lengths are then lined up and held by clamps and tack welded in four places around the circumference, as many lengths as can be handled conveniently, depending on the nature of the country, being tacked together to make a section. The tack welder is followed by the main squad of welders, and the pipes are rolled on the rollers by assistants using chain wrenches, so that the welding of the joint is entirely done in the flat position; hence the name *roll welding*.

After careful inspection, each welded section is lifted off the rollers by tractor-driven derricks and rested on timber baulks, either over or near the trench in which it is to be laid. The sections are then *bell hole* welded together. The operator welds right down the pipe, the top portion being done downhand, the sides vertical, and the underside as an overhead weld. Electrodes of 4 and 5 mm diameter are used in this type of weld.

Stove pipe welding (see also Appendix 9)

This type of welding has a different technique from conventional positional welding methods and has enabled steel pipelines to be laid across long distances at high rates. The vertically downward technique is used, welding from 12 o'clock to 6 o'clock in multiple runs.

Cellulose or cellulose–iron powder coated electrodes are used. These give a high burn-off rate, forceful arc and a light, fast-freezing slag and are very suitable for the vertical downward technique. The coating provides a gas shield which is less affected by wind than other electrodes but, generally, welding should not be carried out where the quality of the completed weld would be impaired by prevailing weather conditions, which may include rain, blowing sand and high winds. Weather protection equipment can be used wherever practicable.

Preparation is usually with 60 between weld faces, increased sometimes to 70 with a 1.5 mm root face and 1.5 mm root gap; internal alignment clamps are used. The stringer bead is forced with no weave into the root, then the hot pass with increased current fuses the sides and fills up any

burn-through which may have occurred. Filler runs, stripper runs and capping run complete the welding (Fig. 8.39*a*). A diesel driven welding generator with tractor unit or mounted with the pipe laying plant is used with the electrode −ve (reverse polarity).

The welding of pipelines is usually performed by a team of welders; the larger the diameter of pipe, the greater the number of welders. In most cases the welder performs the same type of weld on each successive joint. The first team deposits the stringer bead and then moves on to the next joint. The second team carries out the hot pass, and they are followed by the third with the hot fill and the three teams follow along the pipeline from one joint to another. On a 42″ pipe there could be twelve welders spread over three adjacent joints all welding simultaneously. The first group is followed by further groups of fillers and cappers. It is important that the first three passes are deposited without allowing the previous one to cool.

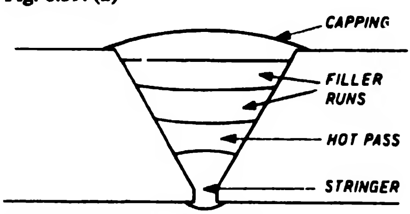
Note. The wire brushes used are of strong stainless steel wire and power driven. As the wire is so strong there must be adequate protection of eyes and face by using a transparent thick face mask.

For clarity Fig. 8.39*a* and *b* shows the various passes and the clock face, while Fig. 8.40 shows pipe preparation including the use of backing rings and Fig. 8.41 shows preparation for a cut and shut bend and a gusset bend.

The CO_2 semi-automatic process is also used for pipeline welding. The supply unit is usually an engine-driven generator set and the technique used is similar to the stove pipe method, but it is important to obtain good line-up to avoid defects in the penetration and correct manipulation to avoid cold shuts. Fully automatic orbital pipe welders are also available using the TIG process and are used on pipes from 25 to 65 mm outside diameter.

For full details of the various methods of preparation and welding standards for pipes, the student should refer to BS 2633, class 1: *Steel pipework*, and BS 2971, class 2: *Steel pipelines*; BS 2910: *Radiographic examination of pipe joints*, and BS 938: *Metal arc welding of structural steel tubes*. See also Appendix 9, Low hydrogen electrode, downhill pipe welding.

Fig. 8.39. (*a*)



PREPARATION 60° INCLUDED ANGLE
ROOT GAP 1.6 mm ROOT FACE 1.6 mm.

For river crossings the pipe thickness is increased by 50–100% and the lengths are welded to the length required for the crossing. Each joint is further reinforced by a sleeve, and large clamps bolted to the line serve as anchor points. The line is then laid in a trench in the river bed.

For water lines from 1 to $1\frac{1}{2}$ m diameter, bell and spigot joints are often used. On larger diameter pipes the usual joint is the reinforced butt. The

Fig. 8.39. (*b*) Clock face for reference.

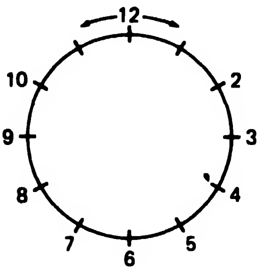


Fig. 8.39. (*c*) Electrode angles (hot fill).

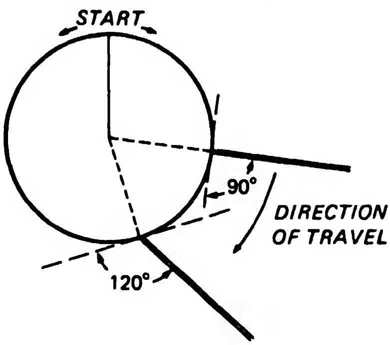
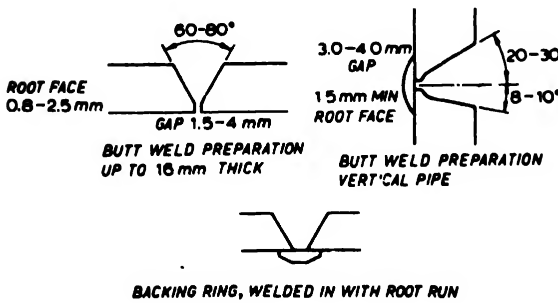


Fig. 8.40



Stove pipe welding - example for pipes of 300-400 mm diameter

Pass	Electrode diam. (mm)	Current (A)	Technique
Stringer bead	3.25	100-130	Preheat to 50 100 C. Strike electrode at 12 o'clock and keep at approximately 90 to line of travel. To control fine penetration, vary electrode angle to 6 o'clock for more to 12 o'clock for less. Use straight touch technique. If necessary someone can control current from generator according to welder's instructions. Arc should be visible on inside of pipe. Do not stop for small 'windows' or burn throughs, which will be eliminated by the hot pass. Grind bead when finished taking slightly more from sides until weld tracks are just visible.
Hot pass	4	180-220	This is deposited immediately after the stringer bead and melts out any inclusions, fills in 'windows' and *must* be deposited on a hot stringer bead which it anneals. It is a light drag weld with a backward and forward 'flicking' movement of the electrode held generally at 60 -70 to the line of travel but this can vary to 90 at 5 o'clock to 6 o'clock and 7 o'clock to 6 o'clock. Rotary wire brushing with a heavy duty power brush completes the pass.
Hot fill	4	160–190	This is deposited immediately after the hot pass, while the pipe is still warm. It cleans the weld profile and adds to the strength of the joint. The electrode is held at 60 to 70 to the line of travel at 12 o'clock, increasing to 120 at 6 o'clock **(see Fig. 8.39*c*)**.
Fill and stripper passes	4	150–190	If the joint has cooled, preheat to 50 to 100 C. All runs are single passes with no weaving and each run is well wire brushed. The electrode is held at 60 -70 to line of travel at 12 o'clock, changing gradually to 90 -100 at 6 o'clock. If the areas between 2 o'clock and 5 o'clock and between 10 o'clock and 7 o'clock are low, stripper passes are made until the weld is of a uniform level.
Capping run	4	130–190	The electrode is held at 60°–80° at 12 o'clock, to 120° at 6 o'clock. A fast side to side weave is permitted, covering not more than $2\frac{1}{2}$ times the diameter of the rod. Lengthening the arc slightly between 5 o'clock and 7 o'clock avoids undercut. Manipulation between 4 o'clock and 8 o'clock can be by a slight 'flicking' technique. After completion the joint is power wire brushed and wrapped in a dry asbestos or similar cloth with waterproof backing and the joint is allowed to cool uniformly.

pipe is V'd on the inside and welded from the inside. A steel reinforcing band is then slipped over the joint and fillet welded in position.

The types of joint are illustrated in Fig. 8.42.

Fig. 8.41. Steel pipe preparation.

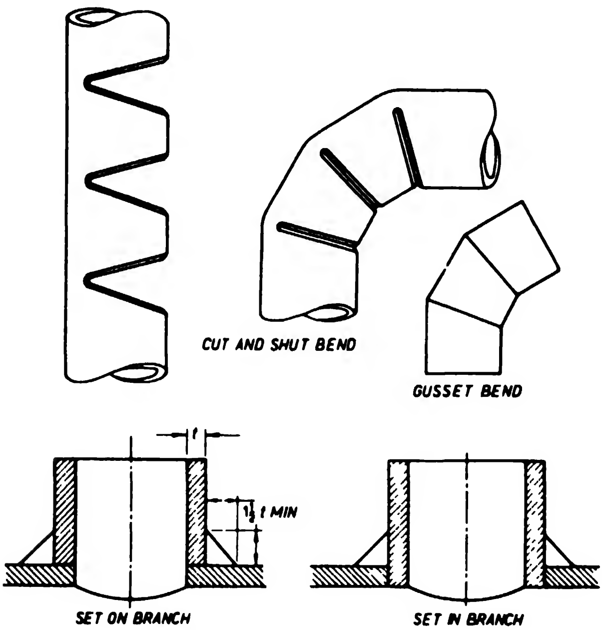
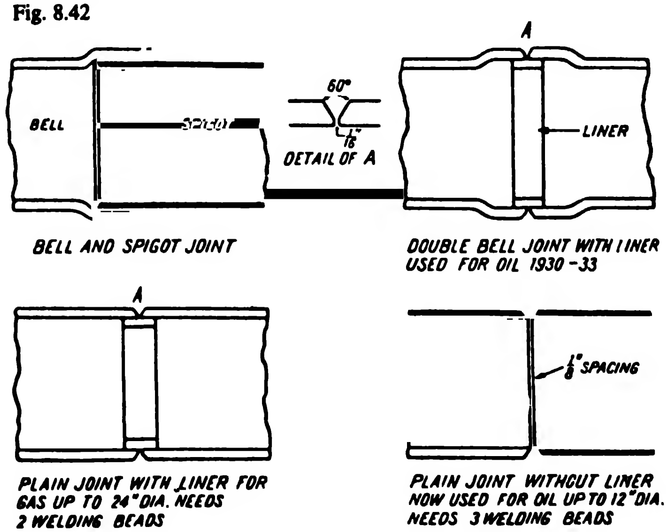


Fig. 8.42



Welding of carbon and carbon–manganese and low-alloy steels

Steels with a carbon content up to about 0.25% carbon (mild steels) are easy to weld and fabricate because, due to their low carbon content, they do not harden by heat treatment so that the weld and HAZ do not have hardened zones even though there is quick cooling. As the carbon content of a steel increases it becomes more difficult to weld, because as the weld cools quickly owing to the quenching action of the adjacent cold mass of metal hardened zones are formed in the HAZ, resulting in brittleness and possible cracking if the joint is under restraint. Pre-heat can be used to overcome this tendency to cracking.

For low-alloy steels the core wire of electrodes may be based on a rimming steel with the alloying elements added to the covering. For stainless steel electrodes the core wire is generally of stainless steel, say 19% Cr/9% Ni, with additions to the covering of alloying elements to make the higher ranges of alloy steels, e.g. 19% Cr, 13% Ni, 1% Mo etc. **(See also p. 93.)**

One or more alloying elements such as Ni, Cr, Mo, Mn, Si, V and Cu are added to steel to increase tensile, impact and shear strength, resistance to corrosion and heat and in some cases to give these improved properties either at high temperature or low (cryogenic) temperatures. The alloying elements do not impair the weldability as would an increase in carbon content, but the steels are susceptible to cracking, and it is this problem which has to be considered in more detail.

Cracking may appear as: (1) delayed cold cracking caused by the presence of H_2; (2) high-temperature liquation cracking (hot cracking); (3) solidification cracking; (4) lamellar tearing; hot cracking and cold cracking have been already considered **on p. 114**. Hot cracks usually appear down the centre of a weld, which is the last part to solidify, while cold cracks occur in the HAZ **(Fig. 8.43)**. These latter may not occur until the weld is subject to stress in service, and since they are often below the metal surface they cannot be seen, so that the first indication of their presence is failure of the joint.

The factors which lead to cold cracking are:

(1) The composition of steel being welded.
(2) The presence of hydrogen.
(3) The rate of cooling of the welded joint.
(4) The degree of restraint (stress) on the joint.

(1) Composition of the steel and carbon equivalent (CE). The tendency to crack increases as the carbon and alloying element content increases, and

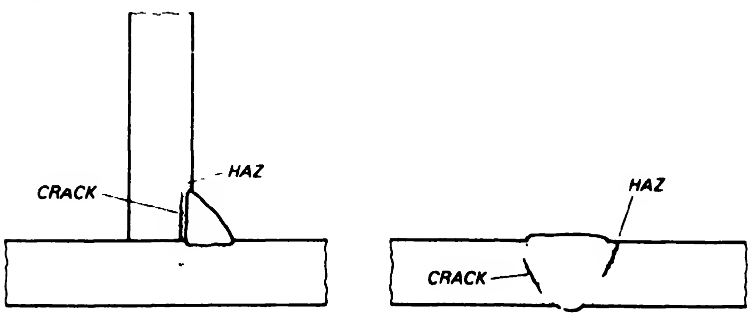
since there is a great variety in the types of steel to be welded it is convenient to convert the varying amounts of alloying elements present in a given steel into terms of a simple equivalent carbon steel, thus giving an indication of the tendency to crack. This 'carbon equivalent' can be calculated from a formula such as the following:

$$CE = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

(which is a variation of the original formula of Dearden and O'Neill) so that to take a simple example, if steel has the following composition: C 0.13%, Mn 0.3%, Ni 0.5%, Cr 1.0%, application of the formula gives a CE of 0.41%.

(2) The presence of hydrogen in the welded zone greatly increases the tendency to crack, the amount of hydrogen present depending upon the type of electrode used and the moisture content of its coating. A rutile coating may have a high moisture content giving up to 30 ml of hydrogen in 100 g of weld metal. The hydrogen diffuses into the HAZ, and on cooling quickly a hard martensitic zone exists with a liability of cracks occurring. Even a small amount of hydrogen present can result in cracking in severely restrained joints. Basic (hydrogen controlled) electrodes correctly dried before use (p. 350) result in a very low hydrogen content. Austenitic stainless steel electrodes deposit weld metal in which the hydrogen is retained and does not diffuse into the HAZ. The weld has a relatively low yield strength and, when stressed, yields and reduces the restraint on the joint, so they are used, for example, to weld steels such as armour plate which may crack when welded with basic-coated mild steel electrodes. Gas-shielded processes using CO_2 or argon–CO_2 mixtures give welds of a very low hydrogen content.

Fig. 8.43



HAZ CRACKING

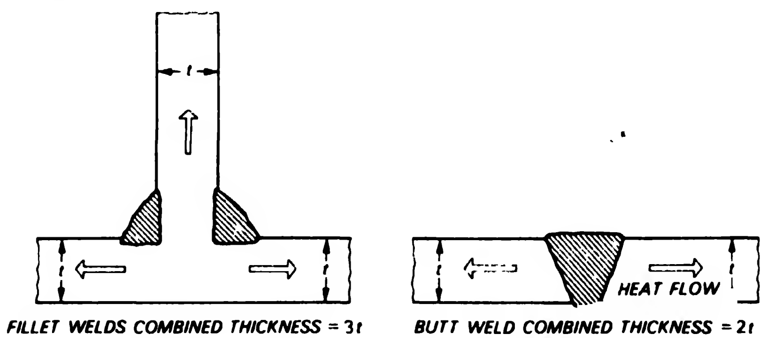
(3) Rate of cooling of the welded zone. The rate of cooling depends upon (1) the heat energy put into the joint and (2) the combined thickness of the metal forming the joint. Arc energy is measured in kilojoules per mm length of weld and can be found from the formula

$$\text{Arc energy (kJ/mm)} = \frac{\text{arc voltage} \times \text{welding current}}{\text{welding speed (mm/s)} \times 1000}$$

The greater the heat input into the joint the slower the rate of cooling so that the use of a large-diameter electrode with high current reduces the quenching effect and thus the cracking tendency. Similarly, smaller-diameter electrodes with lower currents reduce the heat input and give a quicker cooling rate, increasing the tendency to crack due to the formation of hardened zones. Subsequent runs made immediately afterwards are not quenched as is the first run, but if the first or subsequent runs are allowed to cool, conditions then return to those of the first run. For this reason interpass temperature is often stipulated so as to ensure that the weld is not allowed to cool too much before the next run or pass is made. The use of large electrodes with high currents, however, does not necessarily give good impact properties at low temperatures. For cryogenic work it is essential to obtain the greatest possible refining of each layer of weld metal by using smaller-diameter electrodes with stringer or split-weave technique. As the 'combined thickness', that is the total thickness of the sections at the joint, increases, so the cooling rate increases, since there is increased section through which the heat can be conducted away from the joint. The cooling rate of a fillet joint is greater than that for a butt weld of the same section plate since the combined thickness is greater (Fig. 8.44).

(4) Restraint. When a joint is being welded the heat causes expansion, which is followed by rapid cooling. If the joint is part of a very

Fig. 8.44



rigid structure the welded zone has to accommodate the stresses due to these effects and if the weld is not ductile enough, cracking may occur. The degree of restraint is a variable factor and is important when estimating the tendency to crack.

Controlled Thermal Severity (CTS) tests in which degrees of restraint are placed upon the joint to be welded and on which pre- and post-heat can be applied are used to establish the liability to crack. (See Reeve test, pp. 295-6).

Hydrogen cracking can be avoided by (1) using basic hydrogen-controlled electrodes, correctly dried and (2) pre-heating.

The temperature of pre-heat depends upon (1) the CE of the steel, (2) the process used and in the MMA process, the type of electrode (rutile or basic), (3) the type of weld, whether butt or fillet and the run out length (x mm electrode giving y mm weld), (4) the combined thickness of the joint and (5) arc energy.

Reference tables are given in BS 5135 from which the pre-heat temperature can be ascertained from the above variables. Pre-heat temperatures may vary from 0 to 150°C for carbon and carbon–manganese steels and be up to 300 C for higher-carbon low-alloy steels containing chromium and molybdenum. The pre-heating temperature is specified as the temperature of the plate immediately before welding begins and measured for a distance of at least 75 mm on each side of the joint, preferably on the opposite face from that which was heated. The combined thickness is the sum of the plate thickness up to a distance of 75 mm from the joint. If the thickness increases greatly near the 75 mm zone higher combined thickness values should be used and it should be noted that if the whole unit being welded (or up to twice the distance given above) can be pre-heated, pre-heat temperatures can be reduced by about 50°C. Austenitic electrodes can generally be used without pre-heat.

Steels used for cryogenic (low temperature) applications can be carbon–manganese types which have good impact properties down to −30°C and should be welded with electrodes containing nickel; 3% nickel steels are used for temperatures down to −100°C and are welded with matching electrodes whilst 9% nickel steels, used down to −196°C (liquid nitrogen), are welded with nickel chromium–iron electrodes since the 3% nickel electrodes are subject to solidification cracking.

Creep-resistant steels usually contain chromium and molybdenum and occasionally vanadium and are welded with basic-coated low-alloy electrodes with similar chromium and molybdenum content. Two types of cracking are encountered: (1) transverse cracks in the weld metal, (2) HAZ cracking in the parent plate. Pre-heating and interpass temperatures of 200–300°C with post-heat stress relief to about 700°C is usually advisable.

Lamellar tearing

In large, highly stressed structures cracks may occur in the material of the parent plate or the HAZ of a joint, the cracks usually running parallel to the plate surface (**Fig. 8.45**). This is known as lamellar tearing, and it is the result of very severe restraint on the joint and poor ductility, due to the presence of non-metallic inclusions running parallel to the plate surface which are difficult to detect by the usual non-destructive tests. Certain types of joint such as T, cruciform and corner are more susceptible than others. Should lamellar tearing occur the joint design should be modified and tests made on the parent plate to indicate its sensitivity to tearing, while buttering of the surface may also help.

For structural steels in general, basic-coated electrodes are used and current electrode lists of the electrode makers should be consulted for the most up-to-date information.

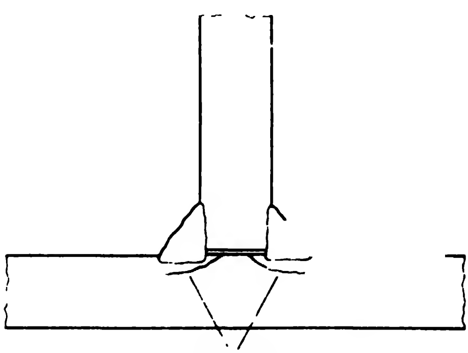
When welding these steels the following points should be observed:

(*a*) When tack welds are used to position the work, as is the general practice, they should be well fused into the weld because, due to the rapid cooling and consequent hardening of the area around the tack weld, cracks may develop.

(*b*) Since the chilling effect is most marked on the first run, careful watch should be kept for any cracks which may develop. Any sealing run applied to the back of the joint should preferably be made either while the joint is still hot, or with a large electrode. The least possible number of runs should be used to fill up the V to minimize distortion.

(*c*) When austenitic rods are used to obtain a weld free from cracks, all the runs should be made with this type of rod and ordinary steel rods not used for subsequent runs. Plates thicker than 15 mm are preferably pre-

Fig. 8.45. Lamellar tearing



heated to 100–200 °C to avoid cracking. Cold work and interrupted welds should generally be pre-heated.

(*d*) The electrode or holder should not be struck momentarily or 'flashed' by design or accident on to the plate prior to welding, since the rapid cooling of the small crater produced leads to areas of intense hardness that may result in fatigue cracks developing.

(*e*) Hard spots in the parent plate may be softened by post-heat applied locally but this may reduce the endurance value of the joint.

Welding of steel castings

The use of steel castings in welded assemblies generally falls under two methods.

(1) Welding steel castings together to form a complex casting that would be difficult to cast as a whole.
(2) Castings and wrought material welded together to form a 'composite' fabrication.

The same rules regarding weldability apply as when welding wrought material. Castings may be in low-carbon-content mild steel, low-alloy steels, or high-alloy steels (such as austenitic manganese and chrome nickel stainless types) and for the alloy steels the same precautions must be taken against cracking as for the wrought form (q.v.). In general the stringer bead technique is used for thick butt welds since it reduces the cracking tendency and horizontal vertical fillets of greater than 8 mm leg length may be multi-run to avoid the tendency towards undercutting of the vertical plate.

Low-alloy steel classifications (British)

Abridged classification for low-alloy steel electrodes for manual metal arc welding. BS 2493 (1985)

Classification. The alloying elements are indicated by their chemical symbols: Mn manganese, Ni nickel, Cr chromium, Mo molybdenum, W tungsten (wolfram), V vanadium. Each symbol is preceded by a number indicating the approximate percentage of the first element given as the alloying addition, e.g. 2CrMoB shows that the alloy will contain 2.0–2.5 % chromium and that the other alloying element is molybdenum (see Table 8). The covering is indicated by B for basic, R for rutile and C for cellulosic. Almost all coverings in this standard are basic (hydrogen controlled) because of the resistance to cracking.

The letter H indicates a hydrogen-controlled electrode and is included for electrodes that deposit not more than 15 ml of diffusible hydrogen per 100 g of weld metal. The manufacturer indicates on the package the

Table 8. *Composition of deposited weld metal*

Composition and covering code	Nearest AWS equivalent	Major alloying elements (%) Cr min	Cr max	Mo min	Mo max	Mn min	Mn max	Ni min	Ni max	Si max	W min	W max	C max	V max
Molybdenum steel electrodes														
MoB	E70XX-A1			0.4	0.7	0.75	1.2			0.6			0.1	
MoC	E70XX-A1			0.4	0.7	0.35	1.2			0.8			0.1	
MoR														
Chromium–molybdenum steel electrodes (for creep applications a maximum copper content of 0.15% is recommended)														
1CrMoLB	E80XX-B2L	1.0	1.8	0.4	0.7	0.5	1.2			0.5			0.05	
1CrMoB	E80XX-B2	1.0	1.5	0.4	0.7	0.5	1.2			0.5			0.1	
1CrMoR		1.0	1.5	0.4	0.7	0.35	1.2			0.3			0.1	
2CrMoLB	E90XX-B3L	2.0	2.5	0.9	1.2	0.5	1.2			0.5			0.05	
2CrMoB	E90XX-B3	2.0	2.5	0.9	1.2	0.5	1.2			0.5			0.1	
2CrMoR		2.0	2.5	0.9	1.2	0.35	1.2			0.3			0.1	
5CrMoB	E502	4.0	6.0	0.4	0.7	0.5	1.0			0.5			0.1	
7CrMoB	E7Cr	6.0	8.0	0.4	0.7	0.5	1.0			0.8			0.1	
9CrMoB	E505	8.0	10.0	0.9	1.2	0.5	1.0			0.8			0.1	
12CrMoB		11.0	12.5	0.8	1.2	0.3	1.0	0.3	0.8	0.8			0.23	0.3
12CrMoVB		11.0	13.0	0.8	1.2	0.3	1.0			0.8			0.23	0.5
12CrMoWVB		11.0	13.0	0.8	1.2	0.5	1.5	0.3	0.8	0.8	0.7	1.0	0.28	0.5

Nickel steel electrodes												
1NiLB	E70XX-C3L					0.3	1.1	0.8	1.2	0.6		0.07
2NiLB	E70XX-C1L					0.3	1.1	2.0	2.75	0.6		0.05
3NiLB	E70XX-C2L					0.5	1.1	2.8	3.75	0.6		0.05
1NiB	E80XX-C3					0.5	1.8	0.8	1.1	0.8		0.1
2NiB	E80XX-C1					0.5	1.2	2.0	2.75	0.8		0.1
3NiB	E80XX-C2					0.5	1.2	2.8	3.75	0.8		0.1
1NiC	E70XX-C3					0.5	1.2	0.8	1.2	0.8		0.15
2NiC	E70XX-C2					0.5	1.2	2.0	2.75	0.8		0.15
Manganese–molybdenum electrodes												
MnMoB	E90XX-D1			0.25	0.45	1.2	1.8			0.8		0.1
2MnMoB	E100XX-D2			0.25	0.45	1.6	2.0			0.8		0.1
High strength low-alloy steel electrodes												
MnNiB	E90XX-M					0.6	1.2	1.0	1.8	0.8		0.1
NiMoB	E100XX-M			0.2	0.5	0.8	1.6	1.2	1.9	0.8		0.1
1NiMoC	E100XX-G			0.2	0.5	0.5	1.2	1.2	1.9	0.8		0.18
2NiMoB	E110XX-M			0.2	0.5	1.3	1.8	1.5	2.5	0.8		0.1
2NiCrMoB	E120XX-M	0.7	1.5	0.2	0.0	1.3	2.2	1.5	2.5	0.8		0.1

Table 9. *American Welding Society (AWS) abridged classification for low-alloy steel covered arc welding electrodes. A5.5–81 (reprinted 1985)*

The higher tensile strength electrodes, such as E8010, which do not have low hydrogen coverings are used for pipe welding and are usually matched to the pipe.

AWS classification	Type of covering	Capable of producing satisfactory welds in position shown	Type of current
E70 series: minimum tensile strength of deposited metal 70000 psi (480 MPa)			
E7010-X[a]	High cellulose sodium	F, V, OH, H	DCEP
E7011-X	High cellulose potassium	F, V, OH, H	AC or DCEP
E7015-X	Low hydrogen sodium	F, V, OH, H	DCEP
E7016-X	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E7018-X	Iron powder low hydrogen	F, V, OH, H	AC or DCEP
E7020-X	High iron oxide	H-fillets	AC or DCEN
		F	AC or DC, either polarity
E7027-X	Iron powder iron oxide	H-fillets	AC or DCEN
		F	AC or DC, either polarity
E80 series: minimum tensile strength of deposited metal 80000 psi (550 MPa)			
E8010-X	High cellulose sodium	F, V, OH, H	DCEP
E8011-X	High cellulose potassium	F, V, OH, H	AC or DCEP
E8013-X	High titania potassium	F, V, OH, H	AC or DC, either polarity
E8015-X	Low hydrogen sodium	F, V, OH, H	DCEP
E8016-X	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E8018-X	Iron powder low hydrogen	F, V, OH, H	AC or DCEP

E90 series: minimum tensile strength of deposited weld metal 90000 psi (620 MPa)			
E9010-X	High cellulose sodium	F, V, OH, H	DCEP
E9011-X	High cellulose potassium	F, V, OH, H	AC or DCEP
E9013-X	High titania potassium	F, V, OH, H	AC or DC, either polarity
E9015-X	High hydrogen sodium	F, V, OH, H	DCEP
E9016-X	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E9018-X	Iron powder low hydrogen	F, V, OH, H	AC or DCEP
E100 series: minimum tensile strength of deposited metal 100000 psi (690 MPa)			
E10010-X	High cellulose sodium	F, V, OH, H	DCEP
E10011-X	High cellulose potassium	F, V, OH, H	AC or DCEP
E10013-X	High titania potassium	F, V, OH, H	AC or DC, either polarity
E10015-X	Low hydrogen sodium	F, V, OH, H	DCEP
E10016-X	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E10018-X	Iron powder, low hydrogen	F, V, OH, H	AC or DCEP
E110 series: minimum tensile strength of deposited weld metal 110000 psi (760 MPa)			
E11015-X	Low hydrogen sodium	F, V, OH, H	DCEP
E11016-X	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E11018-X	Iron powder, low hydrogen	F, V, OH, H	AC or DCEP
E120 series: minimum tensile strength of deposited weld metal 120000 psi (830 MPa)			
E12015-X	Low hydrogen sodium	F, V, OH, H	DCEP
E12016-X	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E12018-X	Iron powder, low hydrogen	F, V, OH, H	AC or DCEP

[a] X stands for the various suffixes A1, B1, C1, etc., which denote the types of chemical composition of the electrodes (see Table 10).

Table 10. *Chemical composition of electrodes*

Suffix	Type of steel	Example	Suffix	Type of steel	Example
A1	Carbon–molybdenum	E7011-A1	C2L	Nickel steel	E7016-C2L
B1	Chromium–molybdenum	E8016-B1	C3[c]	Nickel steel	E8018-C3[c]
B2	Chromium–molybdenum	E8018-B2	NM[d]	Nickel-molybdenum	E8018-NM[d]
B2L	Chromium–molybdenum	E8015-B2L	D1	Manganese–molybdenum	E9018-D1
B3	Chromium–molybdenum	E9016-B3	D3	Manganese–molybdenum	E8016-D3
B3L	Chromium–molybdenum	E9018-B3L	D2	Manganese–molybdenum	E10015-D2
B4L	Chromium–molybdenum	E8015-B4L	G	All other low alloy steel electrodes	E7020-G
B5	Chromium–molybdenum	E8016-B5			
C1	Nickel steel	E8016-C1	M	Military specification	E11018-M
C1L	Nickel steel	E7018-C1L	W	Containing small % copper	E7018-W
C2	Nickel steel	E8018-C2			

L indicates a low carbon steel, generally less than 0.15%.

[c] These classifications conform to those covered by military specifications for similar compositions.

[d] Copper shall be 0.10% max and aluminium 0.05% max for E8018-NM electrodes.

necessary drying conditions for the electrodes that will give the necessary hydrogen levels per 100 g of weld metal (see pp. 350 and 354–5). Electrode diameters are 2, 2.5, 3.2, 4, 5, 6 and 6.3 mm.

Details of the full chemical composition, mechanical and radiographic tests, all weld metal tension test and impact (Charpy) test are given in BS 2493 (1985).

Example. 2NiB. A 2% nickel steel electrode (Ni 2.0–2.75%) with basic covering (AWS E80XX-C1)

Most low-alloy steel electrodes have a core wire of rimming steel (steel that has not been fully deoxidized before casting) with the alloying elements added to the covering. Under certain conditions, such as in pipe welding, the thickness of the covering makes positional welding difficult so the cellulosic covered electrodes have a core wire of the correct alloy steel e.g. chromium–molybdenum type as given in Table 8 (1CrMo, 2CrMo and 5CrMo).

Table giving some of the chief types of metal arc welding electrodes available for welding alloy steels

Electrode	Description and uses
Mild steel heavy duty	Rutile or basic coated for medium and heavy duty fabrications. The latter suitable for carbon and alloy steels and mild steel under restraint and for thick sections and root runs in thick plate.
High-tensile alloy steels	Austenitic rutile or basic coated for high-tensile steels including armour plate and joints between low-alloy and stainless steel and in conditions where pre-heat is not possible to avoid cracking.
Structural steels	Basic coated for high-strength structural steels 300 425 N mm^{-2} tensile strength and for copper bearing weathering quality steels.
Notch ductile steels for low-temperature service	Basic coated for steels containing 2 5% Ni, 3% Ni and carbon–manganese steels. Also austenitic high nickel electrodes for 9% Ni steel for service to − 196 C and for dissimilar metal welding and for high Ni Cr alloys for use at elevated temperatures.
Creep-resisting steels	Ferritic, basic coating for (1) 1 25% Cr, 0.5% Mo, (2) 2.5% Cr, 1.0% Mo, (3) 4–6% Cr, 0.5% Mo, steels with pre- and post-heat. Austenitic ferrite controlled for creep-resistant steels and for thick stainless steel sections requiring prolonged heat treatment after welding.
Heat- and corrosion-resisting steels	(1) Rutile or basic coating 19% Cr 9% Ni for extra low carbon stainless steels. (2) Basic coating Nb stabilized for plain or Ti or Nb stabilized 18/8 stainless steels and for a wide range of corrosive- and heat-resisting applications. Variations of these electrodes are for positional welding, smooth finish, and for high deposition rates. (3) Rutile or basic coating Mo bearing for 18/10 Mo steels. (4) Rutile or basic coating, low-carbon austenitic electrodes for low-carbon Mo bearing stainless steels and for welding mild to stainless steel. (5) Basic coating austenitic for heat-resisting 25% Cr, 12% Ni steels, for welding mild and low-alloy steels to stainless steel and for joints in stainless-clad mild steel. (6) Rutile coating austenitic for 23% Cr, 11% Ni heat-resistant steels containing tungsten. (7) Basic coating 25% Cr, 20% Ni (non-magnetic) for welding austenitic 25/20 steels and for mild and low-alloy steels to stainless steel under mild restraint.

Electrode	Description and uses
	(8) **Basic coating 60% Ni, 15% Cr for high-nickel alloys of similar composition (INCOLOY® DS, CRONITE®, etc.) and for welding these alloys and stainless steel to mild steel in low restraint conditions.**
	(9) **A range of electrodes for high-nickel, MONEL®, INCONEL® and INCOLOY® welding. These electrodes are also suitable for a wide range of dissimilar metal welding in these alloys.**
Hard-surfacing and abrasion-resisting alloys	(1) High impact moderate abrasion-resistance rutile coating for rebuilding carbon steel rails, shafts, axles and machine parts subject to abrasive wear. 250 HV.
	(2) Medium impact medium abrasion-resistance rutile or basic coating for rebuilding tractor links and rollers, roller shafts, blades, punching die sets, reasonably machinable. The basic coated electrode gives maximum resistance to underbead cracking and is suitable for resurfacing low-alloy and hardenable steels. 360 HV.
	(3) High abrasion medium impact. (*a*) Rutile or basic coating for hard-surfacing bull-dozer blades, excavator teeth, bucket lips, etc. The basic coated electrode has greater resistance to underbead cracking and eliminates the need for a buffer layer on high-carbon steels. 650 HV. Unmachinable. (*b*) Tubular electrodes depositing chromium carbide. For worn carbon steel such as dredger buckets, excavator shovels etc. Matrix 560 HV. Carbide 1400 HV.
	(4) Severe abrasion moderate impact. (*a*) Tubular electrode depositing fused tungsten carbide giving highest resistance to abrasion with moderate impact resistance. Matrix 600 HV Carbide 1800 HV. (*b*) High-alloy weld deposit for severe abrasion, suitable for use on sand and gravel excavators. Resistant to oxidation. Matrix 700 HV. Carbides 1400 HV.
12–14% Manganese steels	(1) Basic coating, 14% manganese steel (work-hardening) for 12–14% Mn steel parts steel excavators and mining equipment. 240 HV.
	(2) Austenitic stainless steel weld deposit suitable for joining 12–14% Mn steels and for reinforcing and for butter layer for 12–14% Mn electrodes. 250 HV, work-hardened to 500 HV.
	(3) Tubular-type electrodes for hardfacing 12–14 Mn steel parts with high resistance to abrasion and heavy impact. Matrix 640 HV. Carbides 1400 HV.

9

Gas shielded metal arc welding†

*Metal inert gas (MIG), metal active gas (MAG) including CO_2 and mixed gas processes**

The MIG semi-automatic and automatic processes are increasing in use and are displacing some of the more traditional oxy-acetylene and MMA uses.

For repair work on thin sheet as in the motor trade, semi-automatic MIG using argon–CO_2 mixtures has displaced the traditional oxy-acetylene methods because of the reduced heat input and narrower HAZ, thus reducing distortion. For larger fabrication work, mechanical handling equipment with automatic MIG welding heads has revolutionized the fabrication industry, while the advent or robots, which are program controlled and use a fully automated MIG welding head with self-contained wire feed, make less demands on the skilled welder.

Argon could not be used alone as a shielding gas for mild, low-alloy and stainless steel because of arc instability but now sophisticated gas mixtures of argon, helium, CO_2 and oxygen have greatly increased the use of the process. Much research is proceeding regarding the welding of stainless and 9% nickel steels by this method, using magnetic arc oscillation and various gas combinations to obtain positional welds of great reliability and freedom from defects.

The process has very many applications and should be studied by the student as one of the major processes of the future.

It is convenient to consider, under this heading, those applications which involve shielding the arc with argon, helium and carbon dioxide (CO_2) and mixtures of argon with oxygen and/or CO_2 and helium, since the power source and equipment are essentially similar except for the gas supply. These processes fall within the heading MIG/MAG.

* American designation: gas metal-arc welding (GMAW).

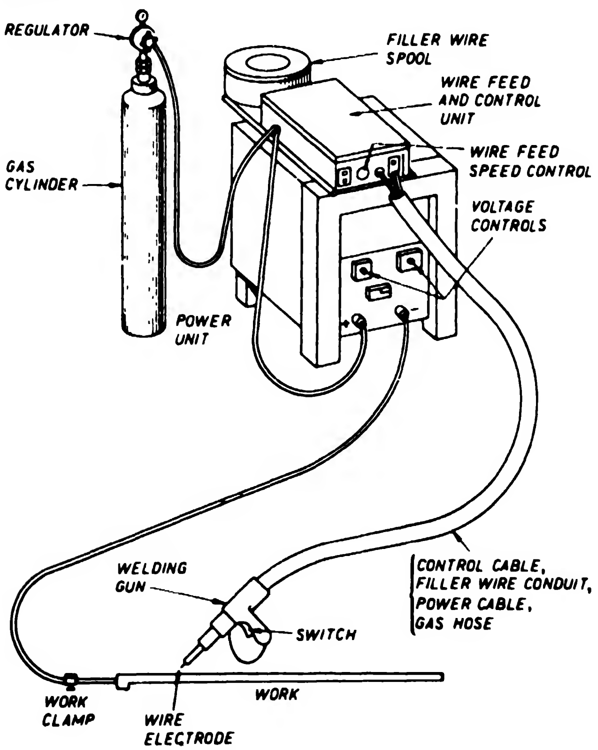
† See also BS 3571 MIG welding of aluminium and aluminium alloys.

With the tungsten inert gas shielded arc welding process, inclusions of tungsten become troublesome with currents above 300 A. The MIG process does not suffer from these disadvantages and larger welding currents giving greater deposition rates can be achieved. The process is suitable for welding aluminium, magnesium alloys, plain and low-alloy steels, stainless and heat-resistant steels, copper and bronze, the variation being filler wire and type of gas shielding the arc.

The consumable electrode of bare wire is carried on a spool and is fed to a manually operated or fully automatic gun through an outer flexible cable by motor-driven rollers of an adjustable speed, and rate of burn-off of the electrode wire must be balanced by the rate of wire feed. Wire feed rate determines the current used.

In addition, a shielding gas or gas mixture is fed to the gun together with welding current supply, cooling water flow and return (if the gun is water cooled) and a control cable from gun switch to control contractors. A d.c. power supply is required with the wire electrode connected to the positive pole (Fig. 9.1).

Fig. 9.1. Components of gas shielded metal arc welding process



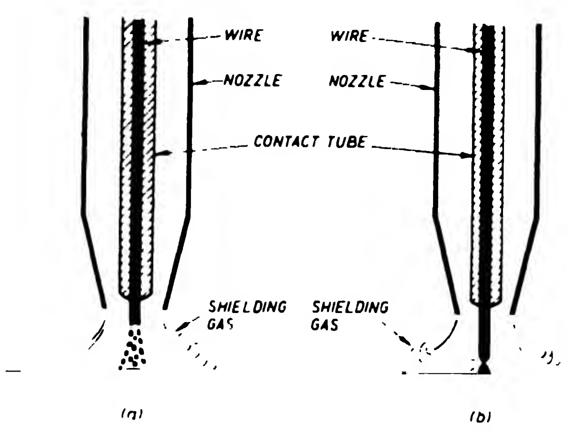
Spray transfer

In manual metal arc welding, metal is transferred in globules or droplets from electrode to work. If the current is increased to the continuously fed, gas-shielded wire, the rate at which the droplets are projected across the arc increases and they become smaller in volume, the transfer occurring in the form of a fine spray.

The type of gas being used as a shield greatly affects the values of current at which spray transfer occurs. Much greater current densities are required with CO_2 than with argon to obtain the same droplet rate. The arc is not extinguished during the operation period so that arc energy output is high, rate of deposition of metal is high, penetration is deep and there is considerable dilution. If currents become excessively high, oxide may be entrapped in the weld metal, producing oxide enfoldment or puckering (in Al). For spray transfer therefore there is a high voltage drop across the arc (30–45 V) and a high current density in the wire electrode, making the process suitable for thicker sections, mostly in the flat position.

The high currents used produce strong magnetic fields and a very directional arc. With argon shielding the forces on the droplets are well balanced during transfer so that they move smoothly from wire to work with little spatter. With CO_2 shielding the forces on the droplet are less balanced so that the arc is less smooth and spatter tendency is greater (**Fig. 9.2**). The power source required for this type of transfer is of the

Fig. 9.2. Types of arc transfer. (*a*) Spray transfer: arc volts 27–45 V. Shielding gases: argon, argon 1 or 2% oxygen, argon 20% CO_2, argon 2% oxygen 5% CO_2. High current and deposition rate, used for flat welding of thicker sections. (*b*) Short-circuit or dip transfer: arc volts 15–22 V. Shielding gases as for spray transfer. Lower heat output and lower deposition rate than spray transfer. Minimizes distortion, low dilution. Used for thinner sections and positional welding of thicker sections.



constant voltage type described later. Spray transfer is also termed free flight transfer.

Short circuit or dip transfer and controlled dip transfer

With lower arc volts and currents transfer takes place in globular form but with intermittent short-circuiting of the arc. The wire feed rate must just exceed the burn-off rate so that the intermittent short-circuiting will occur. When the wire touches the pool and short-circuits the arc there is a momentary rise of current, which must be sufficient to make the wire tip molten, a neck is then formed in it due to magnetic pinch effect and it melts off in the form of a droplet being sucked into the molten pool aided by surface tension. The arc is then re-established, gradually reducing in length as the wire feed rate gains on the burn-off until short-circuiting again occurs (Fig. 9.2). The power source must supply sufficient current on short-circuit to ensure melt-off or otherwise the wire will stick into the pool, and it must also be able to provide sufficient voltage immediately after short-circuit to establish the arc. The short-circuit frequency depends upon arc voltage and current, type of shielding gas, diameter of wire, and the power source characteristic. The heat output of this type of arc is much less than that of the spray transfer type and makes the process very suitable for the welding of thinner sections and for positional welding, in addition to multi-run thicker sections, and it gives much greater welding speed than manual arc on light gauge steel, for example. Dip transfer has the lowest weld metal dilution value of all the arc processes and this method is also pulsed.

Semi-short-circuiting arc

In between the spray transfer and dip transfer ranges is an intermediate range in which the frequency of droplet transfer is approaching that of spray yet at the same time short-circuiting is taking place, but is of very short duration. This semi-short-circuiting arc has certain applications, as for example the automatic welding of medium-thickness steel plate with CO_2 as the shielding gas.

Power supply d.c. and arc control*

There are two methods of automatic arc control:

(1) Constant voltage or potential, known as the self-adjusting arc (CV).

(2) Drooping characteristic or controlled arc (constant current, CC).

The former is more usually employed both on MIG and CO_2 welding plant though the latter may be used very occasionally with larger diameter wires and higher currents and with the flux cored welding process.

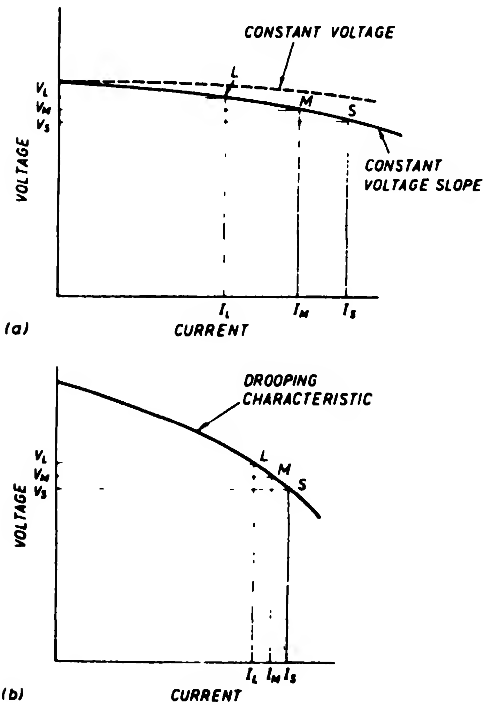
* See Fig. 9.26(*f*), p. 486 and Appendix 13.

Constant voltage d.c. supply

Power can be supplied from a welding generator with level characteristic or from a natural or forced draught cooled three-phase or one-phase transformer and rectifier arranged to give output voltages of approximately 14–50 V and ranges of current according to the output of the unit.

The voltage–current characteristic curve, which should be flat or level in a true constant voltage supply, is usually designed to have a slight droop as shown in **Fig. 9.3*a*.** Evidently this unit maintains an almost constant arc voltage irrespective of the current flowing. The wire feed motor has an adjustable speed control with which the wire feed speed must be pre-set for a given welding operation. Once pre-set the motor feeds the wire to the arc at constant speed. Supplies for the auxiliaries are generally at 110 V a.c. for the wire feed motor and 25 v a.c. for the torch switch circuit, but some units have a 120 V d.c. supply. For the arc to function correctly the rate of wire feed must be exactly balanced by the burn-off rate to keep the arc length constant. Suppose the normal arc length is that with voltage drop V_M

Fig. 9.3. Volt ampere curves of constant voltage and drooping characteristic sources.



indicated in **Fig. 9.3*a*** at M and the current for this length is I_M amperes. If the arc shortens (manually or due to slight variation in motor speed) to S (the volts drop is now V_S) the current now increases to I_S, increasing the burn-off rate, and the arc is lengthened to M. Similarly if the arc lengthens to L, current decreases to I_L and burn-off rate decreases, and the arc shortens to M.

Evidently the gradient of slope of the output curve affects the welding characteristics and slope-controlled units are produced in which the gradient or steepness of the slope can be varied as required and the correct slope selected for given welding conditions.

Drooping characteristic d.c. supply

With this system the d.c. supply is obtained from a welding generator with a drooping characteristic or more usually from a transformer–rectifier unit. If a.c. is required it is supplied at the correct voltages from a transformer.

The characteristic curve of this type of supply (**Fig. 9.3*b***) shows that the voltage falls considerably as the current increases, hence the name. If normal arc length M has volts drop V_M and if the arc length increases to L, the volts drop increases substantially to V_L. If the arc is shortened the volts drop falls to V_S while the current does not vary greatly, hence the name constant current which is often given to this type of supply. The variations in voltage due to changing arc length are fed through control gear to the wire feed motor, the speed of which is thus varied so as to keep a constant arc length, the motor speeding up as the arc lengthens and slowing down as the arc shortens. With this system, therefore, the welding current must be selected for given welding conditions and the control circuits are more complicated than those for the constant voltage method.

Power source–dip transfer (or short-circuit transfer)

In order to keep stable welding conditions with a low voltage arc (17–20 V) which is being rapidly short-circuited, the power source must have the right characteristics. If the short-circuit current is low the electrode will freeze to the plate when welding with low currents and voltages. If the short-circuit current is too high a hole may be formed in the plate or excessive spatter may occur due to scattering of the arc pool when the arc is re-established. The power supply must fulfil the following conditions:

(1) During short-circuit the current must increase enough to melt the wire tip but not so much that it causes spatter when the arc is re-established.

(2) The inductance in the circuit must store enough energy during short-circuit to help to start the arc again and assist in maintaining it during the decay of voltage and current. If an inductive reactor or choke connected in the arc circuit when the arc is short-circuited the current does not rise to a maximum immediately, so the effect of the choke is to limit the rate of rise of current, and the amount by which it limits it depends upon the inductance of the choke. This limitation is used to prevent spatter in CO_2 welding. When the current reaches its maximum value there is maximum energy stored in the magnetic field of the choke. When the droplet necks off in dip transfer and the arc is re-struck, the current is reduced and hence the magnetic field of the choke is reduced in strength, the reduction in energy being fed into the circuit helping to re-establish the arc. If the circuit is to have variable inductance so that the choke can be adjusted to given conditions the coil is usually tapped to a selector switch and by varying the number of turns in circuit the inductive effect is varied. The inductance can also be varied by using a variable air gap in the magnetic circuit of the choke.

To summarize: the voltage of a constant voltage power source remains substantially constant as the current increases. In the case of a welding power unit the voltage drop may be one or two volts per hundred amperes of welding current, and in these circumstances the short-circuit current will be high. This presents no problem with spray transfer where the current adjusts to arc length and thus prevents short-circuiting, but in the case of short-circuiting (dip) transfer, excessive short-circuit currents would cause much spatter.

The steeper the slope of the power unit volt ampere characteristic curve the less the short-circuit current and the less the 'pinch effect' (which is the resultant inward magnetic force acting on the molten metal in transfer) so that spatter is reduced. Too much reduction of the short-circuit current, however, may lead to difficulty in arc initiation and stubbing. Power units are available having slope control so that the slope can be varied to suit welding conditions, and the control can be by tapped reactor or by infinitely variable reactor, the power factor of the latter being better than that of the former.

Three variables can thus be provided on the power unit - slope control, voltage and inductance. Machines with all three controls give the most accurate control of welding conditions but are more expensive and require more setting than those with only two variables, slope-voltage or voltage inductance. In general, units with voltage inductance control offer

better characteristics for short-circuit transfer than those with slope–voltage control. For spray transfer conditions all types perform well, with the proviso that for aluminium welding the unit should have sufficient slope.

Transformer–rectifier power unit

Fig. 9.4*a* shows a transformer–rectifier power unit with output voltages by tapped transformer giving various wire speeds and feeds.

Fig. 9.4*b* shows an engine driven transformer–rectifier unit.

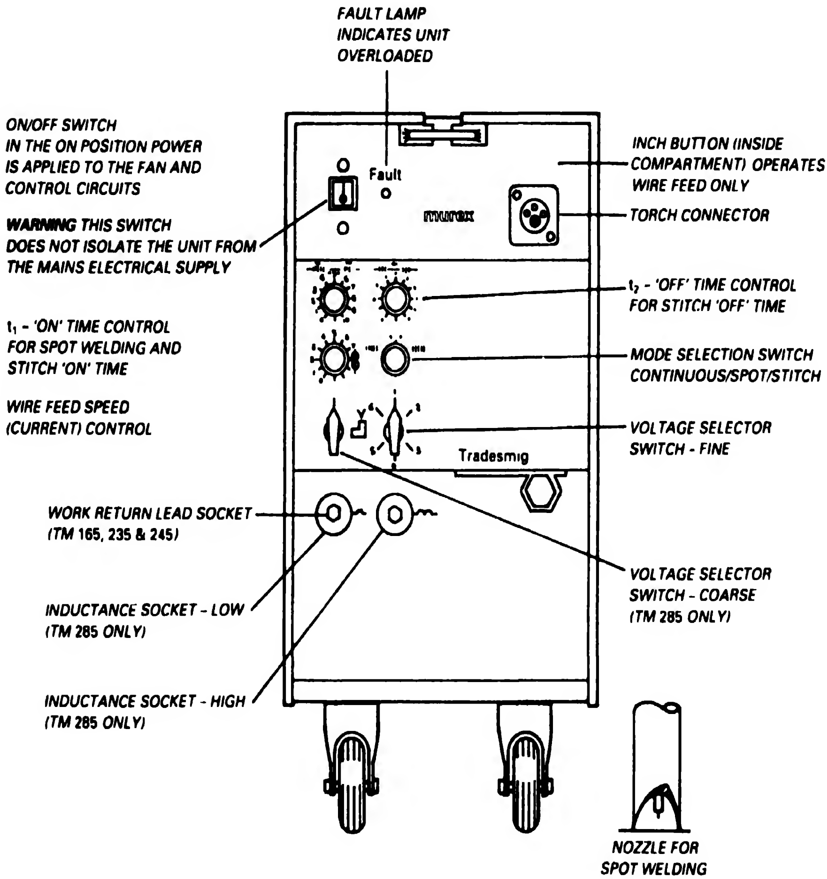
Fig. 9.5 shows a general method of connection for 3 phase input.

Wire feed and control cabinet

In the most popular system the wire is pushed through the guide tube to the gun and is particularly suitable for hard wires such as steel and stainless and heat-resistant steel. In the second method the motor is in the handle of the gun (Fig. 9.7*f*) and the wire is pulled from the reel through the guide tube to the gun. This allows a greater distance to be worked from power unit to welding position and is particularly useful for aluminium as the roll pressure is not so great but the reel capacity is smaller. In some cases a combination of these two methods, the push–pull type, is used applicable to both hard and soft wires but higher in initial cost.

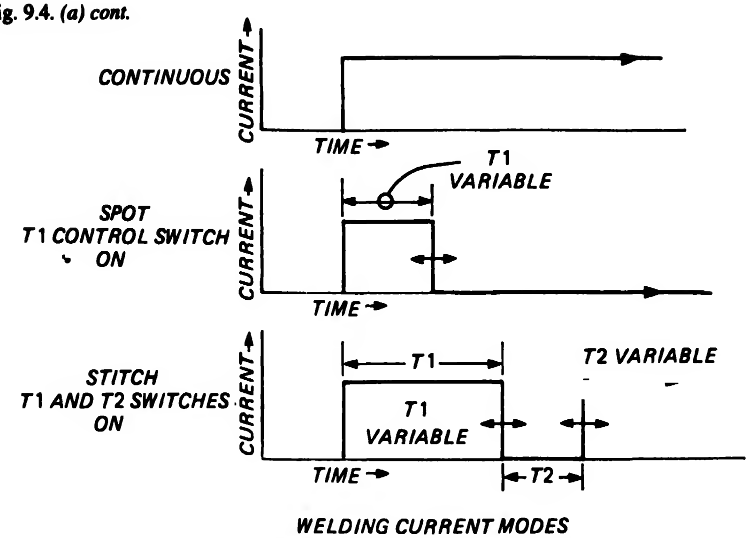
In the push type, the most popular, the wires of diameter 0.8, 1.0, 1.2, 1.6, 2.4 mm hard and 1.2, 1.6, 2.4 soft, and 3.2 mm flux cored are supplied on reels of approximately 15, 25, 30 kg, etc., and are supplied for steel, low-alloy steel, creep-resistant and weathering steels, stainless heat-resistant steel, hard facing, aluminium, bronze and copper. The wire passes between motor-driven feed and pressure rollers which may have serrations or grooves to provide grip and which drive the wire at speeds between 2.5 and 15 m per min. The pressure on this drive can be varied and care must be taken that there is enough pressure to prevent slipping, in which case the arc lengthens and may burn back to the contact tube, and on the other hand that the pressure is not so great as to cause distortion of the wire or the flaking off of small metal particles with consequent increased wear on the guide tubes and possibility of jamming. Some units have a steel channel between feed and pressure rollers through which the wire passes and which helps prevent kinking. Other machines have a small removable magnet fixed after the wire drive to pick up such particles when ferrous wires are used. The flexible outer cables through which the wire is fed to the gun may have nylon liners for smoother feeding of fine wire sizes. The cabinet houses the wire drive motor and assembly, gas and cooling water valves and main

Fig. 9.4. (*a*) A 380–415 V 3-phase 50 Hz transformer–rectifier power source with integral wire feed system, 235 A. Other capacities available for single and 3-phase, e.g. 135 A, 165 A, 245 A, 285 A. CO_2- and Ar-rich gases. Continuous, spot and stitch modes. Capability: mild steel up to 10 mm thick, stainless steel, and aluminium. Spot 0.5–1.0 mm thick, output current 40–230 A at 15–25 arc volts. At 60% duty cycle 155 A. Weight 75 kg. (See Appendix 13, p.771, for a photograph of a similar unit.)



For spot welding the nozzle is changed for one that has a cut-away end, so that the contact tip is distanced from the work. Upon pressing the torch switch the wire moves down to the work to make the spot weld. The size of spot weld depends upon the thickness of plate being spot welded and is determined by the time setting on switch 1.

Fig. 9.4. *(a) cont.*



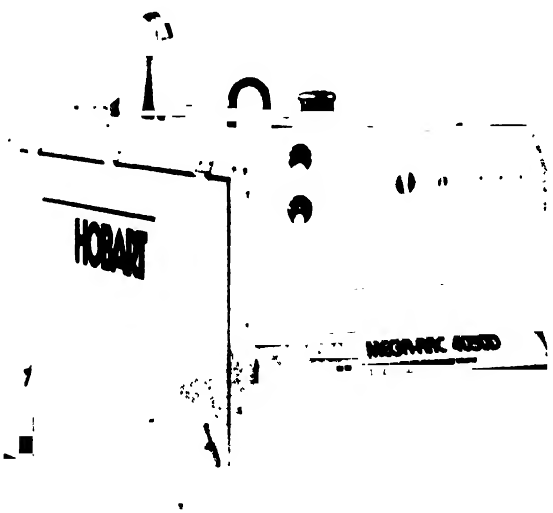
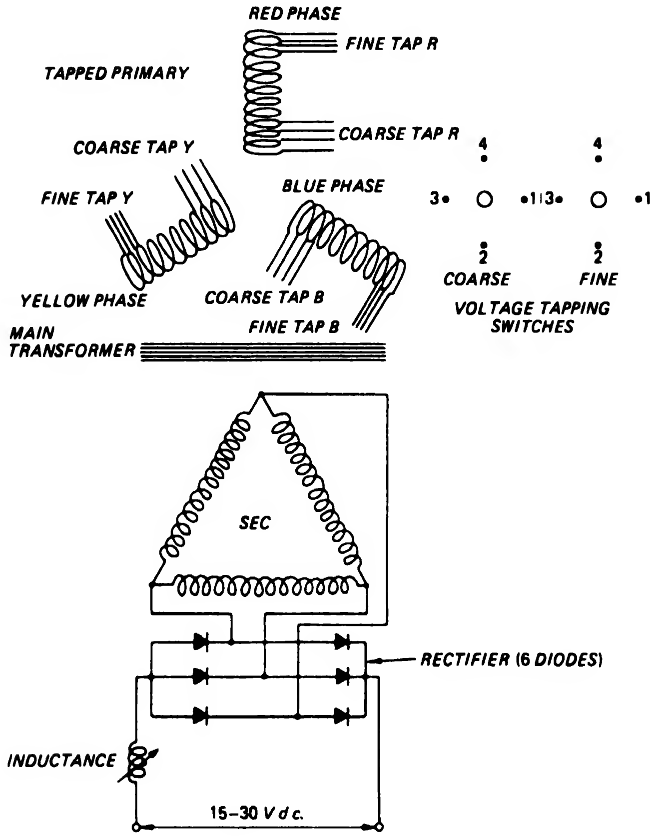


Fig. 9.4. (*b*) Mega-arc diesel engine driven, 1800 rpm. Water-cooled Perkins engine. Models for 400 A, 450 A and 500 A at 60 % duty cycle. High and low current ranges, OCV 75. Auxiliary power 115/230 receptacle. For d.c. MMA, TIG, flux core with or without gas, solid wire spray transfer, and some dip transfer applications using 75 % Ar, 25 % CO_2. Arc force control. Optional remote control.

current contactor (controlled from the switch on the gun or automatic head) and the wire speed control, which is also the current control, is pre-set manually or automatically (Figs. 9.6*a* and *b*). There are also gas purging and inching switches, and in some units regenerative braking on the wire drive motor prevents over-run at the end of a weld.

Fig. 9.5. 3-phase rectification (capacitors not shown).



Sets are now also available with programmable power sources. Using known quantities such as amperes, seconds, metres per minute feed, the welding program is divided into a chosen number of sections and the welding parameters as indicated previously are used to program the computer which controls the welding source. The program can be stored in the computer memory of up to say 50 numbered welding programs or it can be stored on a separate magnetic data card for external storage or use on another unit. By pressing the correct numbers on the keyboard of the unit any programs can be selected and the chosen program begins, controlling welding current, shielding and backing gas, gas pre-flow, wire feed speed, arc length, pulsed welding current and slope control, etc. All safety controls are fitted and changes in the welding program can be made without affecting other data.

Fig. 9.6. (*a*) Transmig 400 inverter for MIG/MAG, MMA (stick), d c TIG, with pulsed MIG Input 380–415 V, 50–60 Hz, 3-phase with wire feed. Remote control optional. 60–70 OCV MIG/MAG, and 65–75 OCV with MMA and TIG. At 60% duty cycle 315 A with 50 arc volts. At 40% duty cycle 400 A at 36 V Stable arc, low spatter, HF start Good positional capability. Remote control, pulse unit and water adapter. Weight 48 kg, the inverter giving weight reduction. **(See Appendix 13, p. 772, for photograph, and Chapter 5 for complete description of the inverter.)**

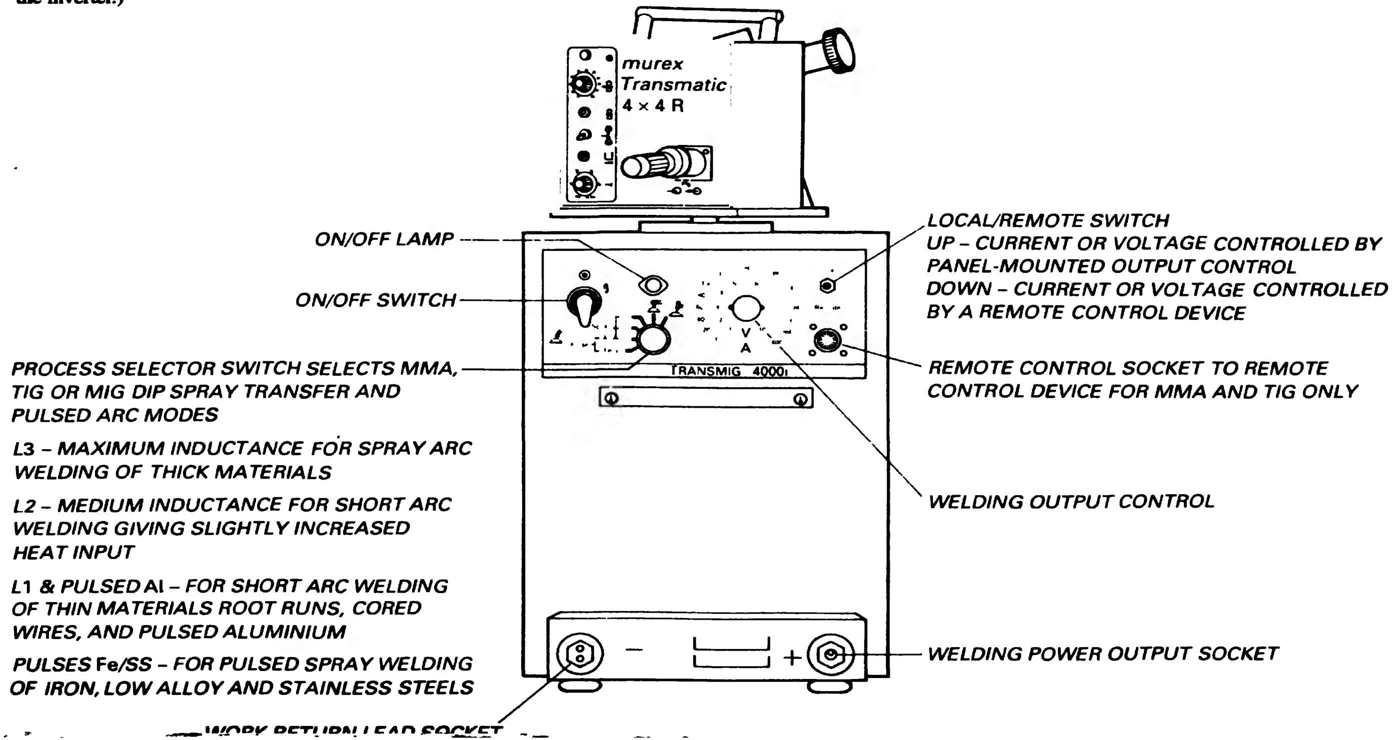
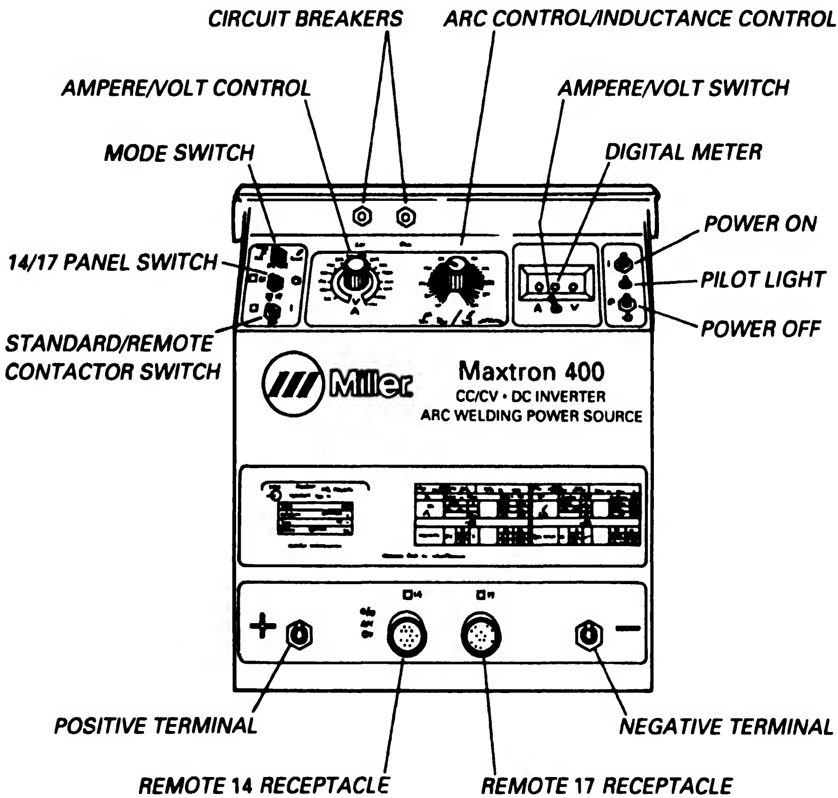


Fig. 9.6. (*b*) Tectron or Maxtron 400, CC/CV inverter power source. Input 380–415 V. Output 400 A at 36 V (60% duty cycle) OCV 80. Solid state power and control. Suitable for MMA (GMAW), MIG (SMAW) with pulsed spray for MIG/MAG, TIG (GTAW) and pulsed arc with 0.25–25 pulses/sec; scratch start and flux cored arc welding (FCAW). Can be used with all types of wire feeders. Remote control when required. Line voltage compensation 10%. Two-position process switch for selected welding method. Voltage range in CV mode 10–36. Amperage in CC mode 3–400. Weight 51 kg. This unit is termed Tectron in Europe. See Appendix 13 for illustration of unit, c/w wire feed etc.



The inverter

The inverter power source, is used in the latest modern technology for MIG, MAG, TIG etc. The a.c. from the mains is rectified to d.c., passed into the inverter, converted to high frequency square wave d.c., transformed to HF a.c., passed into a transformer still at HF and brought down to a voltage suitable for welding. It then passes through a reactor which smooths the current and a final rectifier gives d.c. for the arc. A final electronic switching arrangement enables the welder to select either d.c. or a.c. at high frequency and the resulting arc is easy to strike, smooth and stable. This method has many advantages compared with the conventional power unit. The subject is dealt with in Chapter 5.

Torch (Fig. 9.7*a–g*). To the welding torch of either gooseneck or pistol type or an automatic head are connected the following supplies:

(1) Flexible cable through which the wire electrode is fed.
(2) Tubes carrying shielding gas and cooling water flow and return (if water cooled).
(3) Cable carrying the main current and control wire cable.

A centrally placed and replaceable contact tube or tip screws into the torch head and is chosen to be a sliding fit in the diameter of wire being used. Contact from power unit to welding wire is made at the contact tube, which must be removed and cleaned at intervals and replaced as required. A metal shield or nozzle surrounds the wire emerging from the tube through which the shielding gas flows and surrounds arc and molten pool. Air-cooled torches are used up to 400 A and water-cooled up to 600 A. In the latter type the cooling water return flows around the copper cable carrying the welding current and thus this cable can be of smaller cross-sectional area and thus lighter and more flexible. A water-cooled fuse in the circuit ensures that the water-cooling flow must be in operation before welding commences and thus protects the circuit.

The wire feed can be contained in the head (Fig. 9.7*f*) only when the feed is by 'pull' or there can be a 'pull' torch unit, a 'push' unit, and a control box. These units handle wires of 0.8, 1.0, 1.2 or 1.6 mm diameter in soft aluminium or 0.8, 1.0 and 1.2 mm in hard steel wire, the unit being rated at 300 A. Pre-weld and post-weld gas flows are operated by the gas trigger and operate automatically. They operate from the standard MIG or CO_2 rectifier units and are suitable for mixed gas or CO_2 shielding, the very compact bulk greatly adding to their usefulness since they have a very large working radius.

Fig. 9.7. (*a*) Straight-necked, air-cooled torch, variable in length by 38 mm. Current: at 75% duty cycle, 300 A with argon-rich gases, 500 A with CO_2; at 50% duty cycle, 350 and 550 A respectively. Wires: hard and soft, 1.2 and 1.6 mm, flux cored 1.6, 2.0 and 2.4 mm. (*b*) air-cooled torch, 45° neck angle. Current: at 75% duty cycle 300 A with argon-rich gases, 350 A with CO_2; at 50% duty cycle 350 A and 400 A respectively. Wires: hard 0.8, 1.0, 1.2 and 1.6 mm, soft 1.2 and 1.6 mm, flux cored, 1.6 mm. (*c*) Air-cooled torch, 60° neck angle. Current: at 75% duty cycle 300 A with argon-rich gases, 350 A with CO_2; at 50% duty cycle 350 and 400 A respectively. Wires: hard 0.8, 1.0, 1.2 and 1.6 mm.

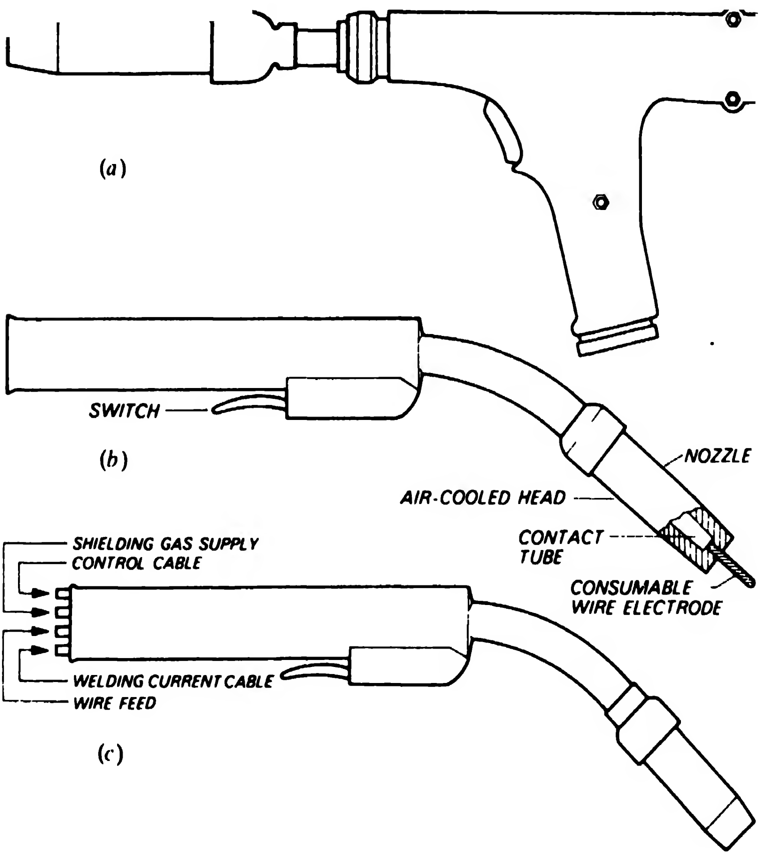


Fig. 9.7. (*d*) MIG welding guns: 600 A, 400 A, 300 A.

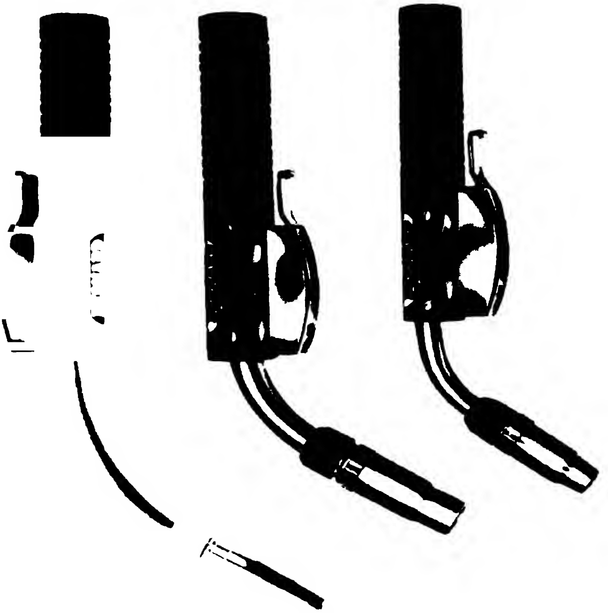


Fig. 9.7. (*e*) 400 A gun showing 'quick disconnect'

Fig. 9.7. (*f*) Welding torch with air motor for wire feed drive built into the handle. Speed of motor is set by means of a knob which controls an air valve Guns can be fitted with swan necks rotatable through 360 . Available in sizes up to 400 A, these latter have a heat shield fitted to protect the hand. A fume extraction unit is also fitted.

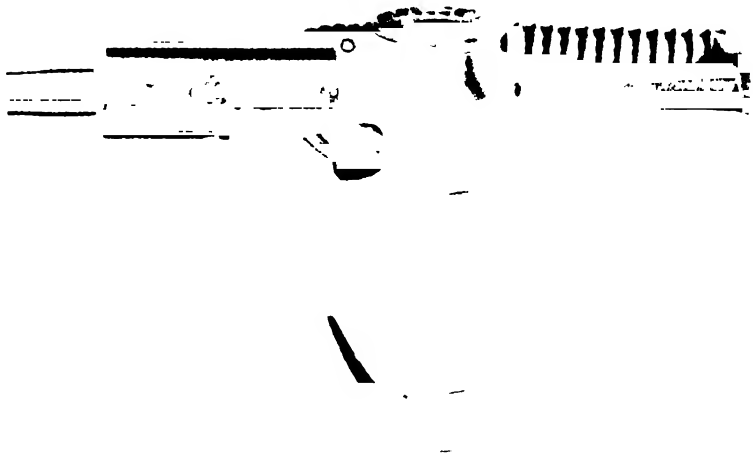
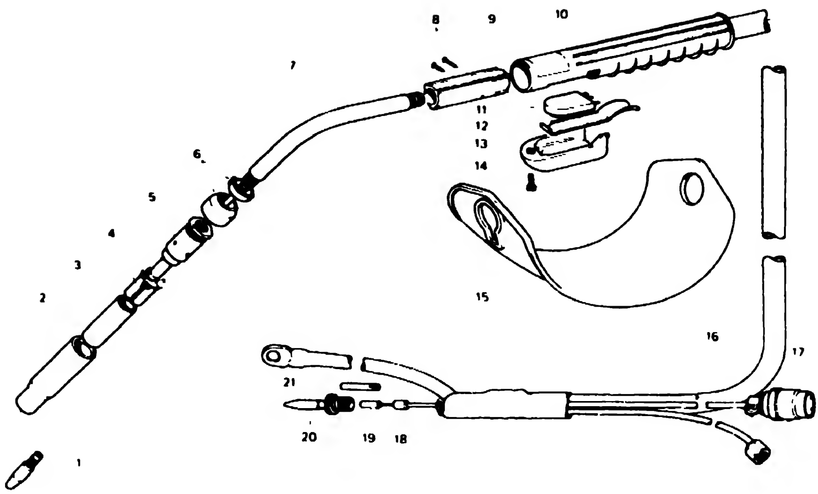


Fig. 9.7. (*g*) Torch with fume extraction unit

Fig. 9.7. (*h*) Welding torch or gun.



1 Contact tip for 1 0, 1 2 and 1 6 mm hard and soft wire, 1 6, 2 0 and 2 4 mm tubular wire
2 Nozzle
3 Nozzle insulator
4 Nozzle spring clip
5 Torch head
6 Head insulator and O clip
7 Neck
8 Self-tapping screw
9 Spider
10 Handle mounting
11 Microswitch
12 Switch lever
13 Switch housing
14 Screw
15 Heat shield
16 Integrated cable
17 Plug 7 pin
18 Basic liner
19 Liner, 1 2, 1 6 mm soft wire, 1 2, 1 6 mm hard wire, 1 6, 2 0 mm tubular wire
20 Outlet guide, 1 2, 1 6 mm soft wire, 1 2, 1 6 mm hard wire, 1 6, 2 0 2 4 mm tubular wire
21 Collet (for soft wire outlet guides)

Gases

Since CO_2 and oxygen are not inert gases, the title metallic inert gas is not true when either of these gases is mixed with argon or CO_2 is used on its own. The title *metallic active gas* (MAG) is sometimes used in these cases

Argon, Ar. Commercial grade purity argon (99.996%) is obtained by fractional distillation of liquid air from the atmosphere, in which it is present to about 1% (0.932%) by volume. It is supplied in blue-painted cylinders containing 1.7, 2.0, 8.48 and 9.66 m^3 of gas at 175 or 200 bar maximum pressure or from bulk supply. It is used as a shielding gas because it is chemically inert and forms no compounds.

Carbon dioxide, CO_2. This is produced as a by-product of industrial processes such as the manufacture of ammonia, from the burning of fuels in an oxygen-rich atmosphere or from the fermentation processes in alcohol production, and is supplied in black-painted steel cylinders containing up to 35 kg of liquid CO_2.* To avoid increase of water vapour above the limit of 0.015% in the gas as the cylinder is emptied, a dip tube or syphon is fitted so that the liquid CO_2 is drawn from the cylinder, producing little fall in temperature **Fig. 9.8** shows a CO_2 vaporizer or heater with pressure reducing regulator and ball type flowmeter. A cartridge type electric heating element at 110 V is in direct contact with the liquid CO_2 to vaporize it The 150 W version gives a flow rate of 21 litres min while the 200 W version gives 28 litres min. A neon warning light connected via a thermostat indicates when the element is heating and is extinguished when the heater has warmed up sufficiently. The syphon cylinder has a white longitudinal stripe down the black cylinder while the non-syphon cylinder, used when the volume of CO_2 to be taken from it is less than 15 litres min, is all black. Manifold cylinders can be fed into a single vaporizer, and if the supply is in a bulk storage tank this is fed into an evaporator, and then fed to the welding points at correct pressure as with bulk argon and oxygen supplies

Helium, He. Atomic weight 4, liquifying point − 268 °C, is thus much lighter than argon, atomic weight 40. It is present in the atmosphere in extremely small quantities but is found in association with natural gas in

* The cylinder pressure depends upon the temperature being approximately 33 bar at 0 °C and 50 bar at 1[illegible] °C

Texas, Oklahoma, Kansas, Alberta, etc., which are the main sources of supply. There is little associated with North Sea gas. Being lighter it requires a greater flow rate than argon and has a 'hotter' arc which may give rise to certain health hazards. Cylinder identifying colour is brown.

Oxygen, O_2. Atomic weight 16, boiling point − 183 C. Obtained by distillation from liquid air. Used in connection with the inert gas in small percentages to assist in wetting and stabilizing the arc. Wetting is discussed on pp. 660–1 under the heading Surface tension.

Application of gases

(1) Argon. Although argon is a very suitable shielding gas for the non-ferrous metals and alloys, if it is used for the welding of steel there exists an unstable negative pole in the work-piece (the wire being positive) which produces an uneven weld profile. Mixtures of argon and oxygen are selected to give optimum welding conditions for various metals.

Fig. 9.8

(2) Argon + 1% or 2% oxygen. The addition of oxygen as a small percentage to argon gives higher arc temperatures and the oxygen acts as a wetting agent to the molten pool, making it more fluid and stabilizing the arc. It reduces surface tension and produces good fusion and penetration. Argon-rich mixtures such as argon and up to 25% CO_2 with the addition of oxygen make the dip transfer process applicable to positional steel work and to thin sheet. Argon + 1–2% O_2 is used for stainless steel and helium, argon, CO_2 can be used on thin sections similarly and has good weld profile. The argon + 1% mixture is used for stainless steels with spray and pulse methods. Dip transfer is better with argon + 2% oxygen as long as the increased oxidation can be tolerated. The addition of 5% hydrogen is the maximum for titanium-stabilized stainless steel and larger amounts than this increase porosity.

(3) Helium is nearly always found in mixed gases. Because of the greater arc temperature, mixing it with argon, oxygen or CO_2 controls the pool temperature, increases wetting and stabilizes the arc. The higher the helium content the higher the arc voltage and the greater the heat output. It is used in gas mixtures for aluminium, nickel, cupro-nickels, etc., and is particularly applicable to stainless steels with the helium–argon–oxygen or CO_2 mixtures. Helium–argon mixtures are also used for the welding of 9% nickel steels.

(4) Carbon dioxide. Pure CO_2 is the cheapest of the shielding gases and can be used as a shield for welding steel up to 0.4% C and low-alloy steel. Because there is some dissociation of the CO_2 in the arc resulting in carbon monoxide and oxygen being formed, the filler wire is triple deoxidized to prevent porosity, and this adds somewhat to its cost and results in some small areas of slag being present in the finished weld. The droplet rate is less than that with pure argon, the arc voltage drop is higher, and the threshold value for spray transfer much higher than with argon. The forces on the droplets being transferred across the arc are less balanced than with argon–oxygen so that the arc is not as smooth and there is some spatter, the arc conditions being more critical than with argon–oxygen.

Using spray transfer there is a high rate of metal deposition and low-hydrogen properties of the weld metal. The dip transfer process is especially suited for positional work. The process has not displaced the submerged arc and electro-slag methods for welding thick steel sections, but complements them and competes in some fields with the manual metal arc process using iron powder electrodes. It offers the most competitive method for repetitive welding operations, and the use of flux cored wire greatly

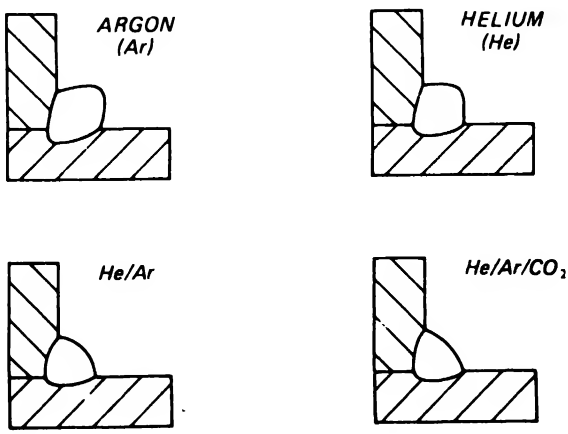
increases the scope of the CO_2 process. Thickness up to 75 mm can be welded in steel using fully automatic heads.

With stainless steel, because of the loss of stabilizers (titanium and niobium) in the CO_2 shielded arc, there is some carbon pick-up resulting in some precipitation of chromium carbide along the grain boundaries and increased carbon content of the weld, reducing the corrosion resistance. Multi-pass runs result in further reduction in corrosion resistance, but with stabilized filler wire and dip transfer on thinner sections satisfactory single-pass welds can be made very economically. Non-toxic, non-flammable paste is available to reduce spatter problems.

(5) Argon + 5% CO_2, Argon + 20% CO_2. The addition of CO_2 to argon for the welding of steel improves the 'wetting' action, reduces surface tension and makes the molten pool more fluid. Both mixtures give excellent results with dip and spray transfer, but the 20% mixture gives poor results with pulse while the 5% mixture gives much better results. The mixtures are more expensive than pure CO_2 but give a smoother, less critical arc with reduced spatter and a flatter weld profile, especially in fillets (Fig. 9.9*b*). The current required for spray transfer is less than for similar conditions with CO_2 and the 5% mixture is suitable for single-run welding of stainless steel with the exception of those with extra low carbon content (L), below 0.06%. Both mixtures contain a small amount of oxygen.

If the CO_2 content is increased above 25% the mixture behaves more and more like pure CO_2. If argon and CO_2 are on bulk supply, mixers enable the percentage to be varied as required. **Figs. 9.9*a* and 9.9*b*** show penetration beads and weld profiles with differing gas mixtures.

Fig. 9.9. (*a*) Stainless steel weld bead profiles, dip transfer



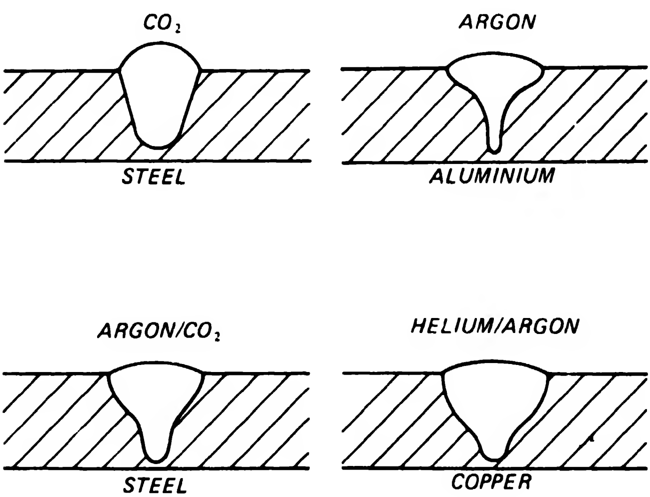
Filler wires*

Note. BS 2901 gives specifications for *Filler rods and wires for inert gas welding.* Part 1, *Ferritic steels;* Part 2, *Austenitic stainless steels;* Part 3, *Copper and copper alloys;* Part 4, *Aluminium and aluminium alloys and magnesium alloys;* Part 5, *Nickel and nickel alloys.*

Filler wires are supplied on convenient reels of 300 mm or more diameter and of varying capacities with wire diameters of 0.6, 0.8, 1.0, 1.2, 1.6, and 2.4 mm. The bare steel wire is usually copper coated to improve conductivity, reduce friction at high feed speeds and minimize corrosion while in stock. Manganese and silicon are used as deoxidizers in many cases but triple deoxidized wire using aluminium, titanium and zirconium gives high-quality welds and is especially suitable for use with CO_2. The following are examples of available steel wires and can be used with argon–5% CO_2 argon 20% CO_2 and CO_2, the designation being to BS 2901 Part 1 (1970).

A 18. General purpose mild steel used for mild and certain low alloy steels. Analysis: 0.12% C; 0.9–1.6% Mn; 0.7–1.2% Si. 0.04% max S and P.

Fig. 9.9. (*b*) Penetration beads spray transfer



* American classification of mild steel welding wires AWS A5.18-69. *Example* E 70S-3. E = electrode, S = bare solid electrode. 3 is a particular classification based on the as manufactured chemical composition

Metal arc gas shielded process. Recommended gases and gas mixtures for various metals and alloys

Metal type	Gas shield	Remarks
Carbon and low-alloy steels	CO_2	For dip transfer, and spray transfer Spatter problems. Use deoxidized wire
	Ar–15/20% CO_2	For dip or spray transfer. Minimum spatter
	Ar–5% CO_2	For dip and spray transfer
	Ar–5% O_2	Spray transfer. High impact properties
	Ar–5% CO_2–O_2 2%	For pulsed arc and thin sections
Stainless steels	Ar–1/2% O_2	Spray transfer
	75 He 23.5% Ar 1.5% CO_2	High quality dip transfer. For thin sections and positional work. Good profile
	He 75%–Ar 24%–O_2 1%	
Aluminium and its alloys	Argon	Stable arc with little spatter
	Helium	Hotter arc, less pre-heat, more spatter
	He 75% Ar 25%	Stable arc, high heat input. Good penetration. Recommended for thicknesses above 16 mm
Magnesium and its alloys	Argon	Stable arc
	He 75% Ar 25%	Hotter arc Less porosity
Copper and its alloys	Argon	For sections up to 9.5 mm thickness
	Helium	
	He 75% Ar 25%	For medium and heavy sections. High heat input
Nickel and its alloys	Argon	Sections up to 9.5 mm thickness. Pulsed arc
	Ar 70% He 30% Ar 25% He 75%	High heat input, less cracking in thicker sections of 9% Ni
Cupro-nickel	Argon	Stable arc
	Ar 70% He 30%	Stable arc with less cracking risk
Titanium, zirconium and alloys	High purity argon	Very reactive metals. High purity shielding gases are essential

Note. O_2 increases the wetting action.

See Appendix 6 for proprietary gases.

The following colour codes are used for cylinders (BS 349, BS 381 C)

Gas or mixture	Colour code
Acetylene, dissolved	Maroon; also with name ACETYLENE.
Argon	Peacock blue.
Argon–CO_2	Peacock blue. Light brunswick green band round middle of cylinder.
Argon–hydrogen	Peacock blue. Signal red band round middle of cylinder.
Argon nitrogen	Peacock blue. French grey band round middle of cylinder.
Argon–oxygen	Peacock blue. Black band round middle of cylinder. % of oxygen indicated.
CO_2, commercial vapour withdrawal	Black.
CO_2, commercial liquid withdrawal	Black. Narrow white band down length of cylinder (syphon tube).
Helium	Brown.
Hydrogen	Signal red.
Hydrogen–high purity	Signal red. White circle on shoulder.
Hydrogen–nitrogen	Signal red. French grey band round middle of cylinder.
Nitrogen	French grey. Black cylinder shoulder.
Nitrogen (oxygen free)	French grey. Black cylinder shoulder with white circle.
Nitrogen–CO_2	French grey. Light brunswick green band round middle of cylinder and black cylinder shoulder.
Nitrogen-oxygen	French grey. Black band round middle of cylinder and black cylinder shoulder.
Oxygen, commercial	Black.
Propane	Signal red with name PROPANE.
Air	French grey.
Air–CO_2	French grey. Light brunswick green band round middle of cylinder.

Note. Colour bands on shoulder of cylinder denote hazard properties. Cylinders having a red band on the shoulder contain a flammable gas; cylinders having a golden yellow band on the shoulder contain a toxic (poisonous) gas. Cylinders having a red band on the upper shoulder and a yellow band on the lower shoulder contain a flammable and toxic gas. Carbon monoxide has a red cylinder with a yellow shoulder.

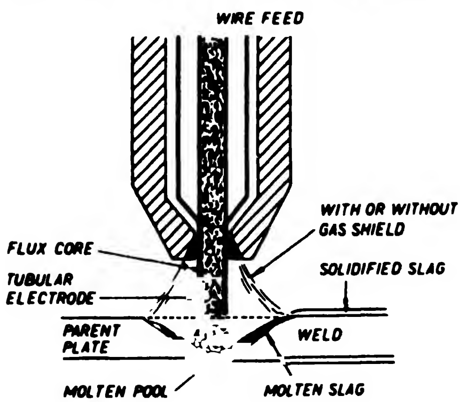
A 15. Triple deoxidized steel wire recommended for pipe welds and root runs in heavy vessel construction. Analysis: 0.12% max. C; 0.9–1.6% Mn; 0.3–0.9% Si; 0.04–0.4% Al; 0.15% max. Ti; 0.15% max. Zr; 0.04% max. S and P.
A31. Molybdenum bearing mild steel wire. Used for most mild-steel applications requiring extra strength; high-tensile and quench and tempered steel; and suitable for offshore pipeline application and root runs in thick joints. Analysis: 0.14% max. C; 1.6–2.1% Mn; 0.5–0.9% Si; 0.4–0.6% Mo; 0.03% max. S and P.

Flux cored and metal powder cored filler wire*

Flux cored and metal powder cored wires, used with a gas shield of CO_2 or argon–5% CO_2 to argon–20% CO_2 give rapid deposition of metal and high-quality welds in steel. Metal powder wire used with argon–20% CO_2 gives a smooth arc with little spatter and is used with wire negative polarity. It can be used for positional work and because of the small amount of slag, which is produced intermittently, there is no need to deslag between runs.

The wire is manufactured from a continuous narrow flat steel strip formed into a U shape which is then filled with flux and formed into a tube. It is then pulled through reducing dies which reduce the diameter and compress the flux uniformly and tightly into a centre core (Fig. 9. 10*a*). It is supplied on reels as for MIG welding in diameters 1.6, 2.0, 2.4, 3.2 mm and

Fig. 9.10. (*a*) Flux cored process with gas shield.



American classification of mild steel tubular welding wires, flux cored arc welding (FCAW), with and without external gas shield *Example* E 70 T-1· E = electrode; 70 = tensile strength of weld metal in 1000lb/sq in. (ksi), T = tubular continuous electrode with powdered flux in core; 1 = gas type and current (1, 2 CO_2 deep; 3, 4, 6, 8 – none, deep· 5 – CO_2 or none, deep, 7 – none, deep; 9 · miscellaneous)

fed to the feed rollers of a MIG type unit. The welding gun can be straight or swan-necked and should be water cooled for currents above 400 A, and the power unit is the same as for MIG welding.

There is deep penetration with smooth weld finish and minimum spatter, and deposition rate is of the order of 10 kg h using 2.4 mm diameter wire. The deep penetration characteristics enable a narrower V preparation to be found for butt joints resulting in a saving of filler metal, and fillet size can be reduced by 15 20%.

Some of the filler wires available are:

(1) Rutile type, steel, giving a smooth arc and good weld appearance with easy slag removal. Its uses are for butt and fillet welds in mild and medium-tensile steel in the flat and horizontal vertical position.
(2) Basic hydrogen-controlled type, steel. This is an all-positional type and gives welds having good low-temperature impact values.
(3) Basic hydrogen-controlled type, steel, with $2\frac{1}{2}$% Ni for applications at 50 C.
(4) Basic hydrogen-controlled type for welding 1% Cr, 0.5% Mo steels.
(5) Basic hydrogen-controlled type for welding 2.25% Cr, 1% Mo steels.

Self-shielded flux cored wire

Self-shielded flux cored wires are used without an additional gas shield and can be usefully employed in outdoor or other on site draughty situations where a cylinder-supplied gas shield would be difficult to establish.

The core of these wires contains powdered metal together with gas-forming compounds and deoxidizers and cleaners. The gas shield formed protects the molten metal through the arc and slag-forming compounds form a slag over the metal during cooling, protecting it during solidification. To help prevent absorption of nitrogen from the atmosphere by the weld pool, additions of elements are made to the flux and electrode wire to effectively reduce the soluble nitrogen.

This process can be used semi- or fully automatically and is particularly useful for on-site work **(Fig. 9.10*b*)**.

Metal cored filler wire

The wire has a core containing metallic powders with minimal slag-forming constituents and there is good recovery rate (95%) with no interpass deslagging. It is used with CO_2 or argon CO_2 gas shield to give

welds with low hydrogen level (less than 5 ml/100 g weld metal). The equipment is similar to that used for MIG welding, and deposition rates are higher than with stick electrodes especially on root runs.

Safety precautions

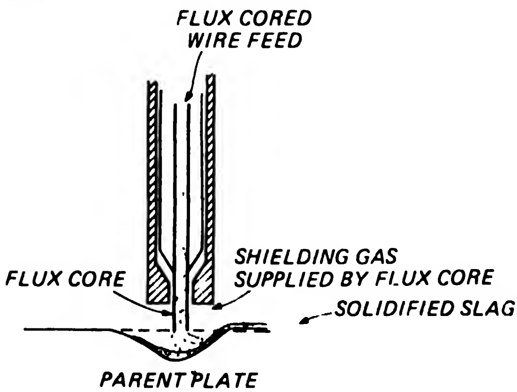
The precautions to be taken are similar to those when metal arc welding, given on p. 374. The BS 679 recommended welding filters are up to 200 A, 10 or 11 EW (electric welding); over 200 A, 12, 13, or 14 EW. When welding in dark surroundings choose the higher shade number, and in bright light the lower shade number. Because there is greater emission of infra-red energy in this process a heat absorbing filter should be used. The student should consult the following publications for further information: BS 679, *Filters for use during welding*, British Standards Institution; *Electric arc welding*, new series no. 38, *Safety, health and welfare*. Published for the Department of Employment by HMSO.

Techniques

There are three methods of initiating the arc. (1) The gun switch operates the gas and water solenoids and when released the wire drive is switched on together with the welding current. (2) The gun switch operates the gas and water solenoids and striking the wire end on the plate operates the wire drive and welding current (known as 'scratch start'). (3) The gun switch operates gas and water solenoids and wire feed with welding current, known as 'punch start'.

The table on p. 457 indicates the various gases and mixtures at present in use. As a general rule dip transfer is used for thinner sections up to 6.4 mm

Fig. 9.10. (*b*) Flux cored process (self-shielded)

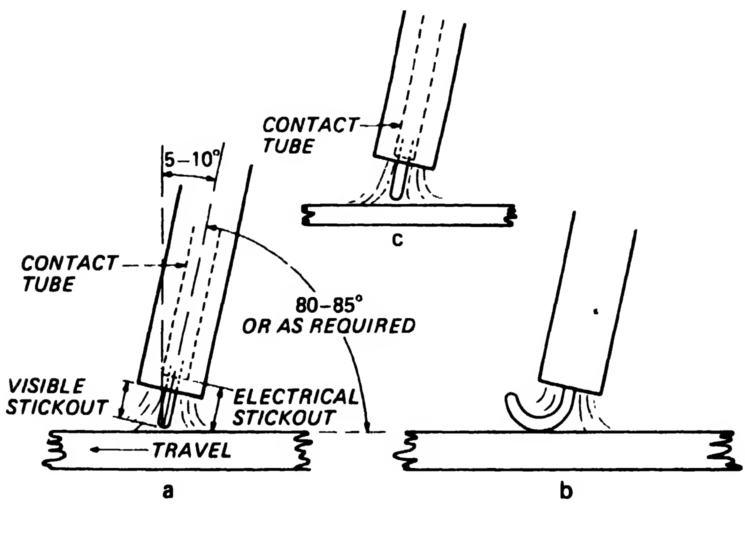


and for positional welding, whilst spray transfer is used for thicker sections. The gun is held at an angle of 80° or slightly less to the line of the weld to obtain a good view of the weld pool, and welding proceeds with the nozzle held 6–12 mm from the work (see **Fig. 9.11*a***). Except under special conditions welding takes place from right to left. If welding takes place for special reasons from left to right the torch has to be held at almost 90° to the line of travel and care must be taken that the gas shield is covering the work.

The further the nozzle is held from the work the less the efficiency of the gas shield, leading to porosity. If the nozzle is held too close to the work spatter may build up, necessitating frequent cleaning of the nozzle, while arcing between nozzle and work can be caused by a bent wire guide tube allowing the wire to touch the nozzle, or by spatter build-up short-circuiting wire and nozzle. If the wire burns back to the guide tube this may be caused by a late start of the wire feed, fouling of the wire in the feed conduit or the feed rolls being too tight. Intermittent wire feed is generally due to insufficient feed roll pressure or looseness due to wear in the rolls. Excessively sharp bends in the flexible guide tubes can also lead to this trouble.

Root runs are performed with no weave and filler runs with as little weave as possible consistent with good fusion since excessive weaving tends to promote porosity. The amount of wire projecting beyond the contact tube is important because the greater the projection, the greater the I^2R effect and the greater the voltage drop, which may reduce the welding current and affect penetration. The least projection commensurate with

Fig. 9.11. (*a*) Angle of torch (flat position) (*b*) Stubbing. (*c*) Dip transfer on thin sheet.



accessibility to the joint being welded should be aimed at. Backing strips which are welded permanently on to the reverse side of the plate by the root run are often used to ensure sound root fusion. Backing bars of copper or ceramics with grooves of the required penetration bead profile can be used and are removed after welding. It is not necessary to back-chip the roof run of the light alloys but with stainless steel this is often done and a sealing run put down. This is a more expensive way compared with efficient back purging. The importance of fit-up in securing continuity and evenness of the penetration bead cannot be over-emphasized.

Flat welds may be slightly tilted to allow the molten metal to flow against the deposited metal and thus give a better profile. If the first run has a very convex profile poor manipulation of the gun may cause cold laps in the subsequent run.

Run-on and run-off plates can be used as in TIG welding to obviate cold start and crater finishing leading to cracks. Slope in and out controls obviate much of this.

Stubbing

If the wire speed is too high the rate of feed of the wire is greater than the burn-off rate and the wire stubs. If a reduction in the wire speed feed rate does not cure the stubbing, check the contact tube for poor current pick-up and replace if necessary **(Fig. 9.11*b*)**.

Burn back control

This operates a variable delay so that the wire burns back to the correct 'stick-out' beyond the nozzle before being switched off. It is then ready for the next welding sequence. Excessive burn back would cause the wire to burn to the contact tip. Varying the stick-out length **(Fig. 9.11*a*)** varies the temperature of the molten pool. Increasing the length gives a somewhat 'cooler' pool and is useful in cases of poor fit-up, for example.

The nearer that the contact tube end is to the outer end of the torch nozzle, the greater the likelihood of the contact tube being contaminated with spatter. With dip transfer, in which the spatter is least, the distance is about 2–3 mm, but for spray transfer it should be in the region of 5–12 mm. The contact tube may even be used slightly projecting from the gas nozzle when being used on thin sheet (e.g. body panels) using dip transfer. This gives a very clear view of the arc but is not recommended as the contact tube becomes rapidly contaminated even when treated with anti-spatter paint or paste and must be cleaned frequently **(Fig. 9.11*c*)**. Whatever the stick-out, the flow of shielding gas should be such that molten pool and immediate surrounding areas are covered.

Positional welding

This is best performed by the dip transfer method since the lower arc energy enables the molten metal to solidify more quickly after deposition. Vertical welds in thin sections are usually made downwards with no weave. Thicker sections are welded upwards or with the root run downwards and subsequent runs upwards, weaving as required. Overhead welding, which is performed only when absolutely necessary, is performed with no weave.

Fillet welds are performed with the gun held backwards to the line of welding, as near as possible to the vertical consistent with a good view of the molten pool, bisecting the angle between the plates and with a contact tip-to-work distance of 16–20 mm (**Fig. 9.12**). On unequal sections the arc is held more towards the thicker section. The root run is performed with no weave and subsequent runs with enough weave to ensure equal fusion on the legs. Tilted fillets give better weld profile and equal leg length more easily.

Some of the filler wires available are:

Note. Except where indicated they can be used with CO_2, argon–5% CO_2 and argon–20% CO_2. CO_2 gives good results with dip transfer whereas the argon mixtures give better weld profile. L indicates 0.08% C or lower.

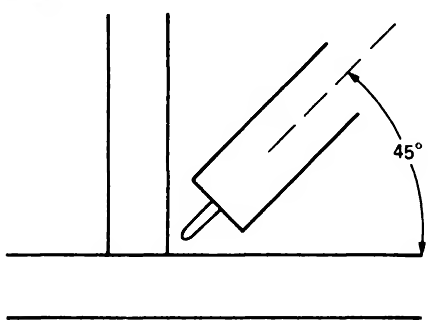
(1) 1.5% Mn, L. Smooth arc, little slag, so no deslagging, Argon–20% CO_2, cored wire +ve.

(2) 1.8% Mn, 0.5% Mo, 0.14% C. High strength mild steels and for highet tensile steels, solid wire +ve.

(3) 1.4% Mn, 0.5% Mo, L. Similar wire to (1) but molybdenum gives extra strength. Argon–20% CO_2, cored wire +ve.

(4) 1.4% Mn, 0.45% Cu, L. A similar wire to (1) but with copper added for weathering steels such as Corten. Use argon–5% or argon–20% CO_2, cored wire +ve.

Fig. 9.12. Angle of torch horizontal vertical fillet



(5) 1.3% Cr, 1.1% Mn, 0.2% Mo, 1.0% Ni, L. High strength welds, tensile strengths of 750 N/mm^2. Rutile basic flux cored wire +ve.
(6) 2.0% Mn, 1.0% Mo, L. Basic flux core with iron powder, creep-resistant steels, cored wire −ve.
(7) 2.2% Cr, 1.0% Mo, 0.12% C. Basic flux core for creep-resistant steels to temperatures of 580°C, solid wire − ve.
(8) 2.2% Ni, L. For low temperatures to −50°C. Good resistance to cracking cored wire −ve, use argon–CO_2 mixtures.

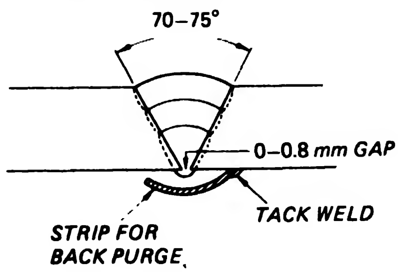
Stainless steels

Preparation angle is usually similar for semi-automatic and automatic welding for butt welds in stainless steel, being 70–80° with a 0–1.5 mm gap (Fig.10.27).Torch angle should be 80–90° with an arc length long enough to prevent spatter but not long enough to introduce instability. All oxides should be removed by stainless steel wire-brushing. Back chipping is usually performed by grinding. With spray transfer using high currents there is considerable dilution effect and welds can only be made flat, but excessive weaving should be avoided as this increases dilution. Direct current with the torch (electrode) positive is used with a shield of argon + 1% o. ygen.

When welding stainless steel of any thickness it is imperative to obtain good penetration and this is only possible if there is a good back purge. Without this the penetration has to be back chipped and a sealing run made which adds considerably to the cost of the joint.

Back purging can be obtained simply by tack welding a strip on the underside of the weld and removing after welding (Fig. 9.13). This uses argon from the torch and reduces oxide formation on the penetration bead. Back purging of tubes can often be done using soluble paper dams or piped bladders which are blown up in position inside the pipe and serve to contain the inert gas on the underside of the weld, thus effecting considerable saving.

Fig. 9.13. Butt welding stainless steel MIG, 99% A 1% O_2, d.c. wire positive. Automatic or semi-automatic.



In the welding of dissimilar metals to stainless steel the shortcircuiting arc (dip transfer) gives much less dilution with lower heat input and is generally preferred. The arc should be kept on the edge of the parent metal next to the molten pool and not in the pool itself, to reduce the tendency to the formation of cold laps. Argon 1–2% oxygen is used as the shielding gas and filler wires should be chosen to match the analysis of the parent metal while allowing for some loss in the transfer across the arc. Examples are given in the table. **Figs. 9.13 and 10.27** give suitable methods of preparation.

Stainless steel filler wires available include the following

BS 2901 Pt 2	AISI	AWS	
308S92	304, 304L	A59 ER308L	Low carbon (0.03% max.) 19.5–22% Cr, 9–11% Ni, suitable for welding 18% Cr, 8% Ni steels including low carbon types.
	321, 347		18% Cr, 8 Ni, Nb stabilized at temperatures up to 400°C
316S92	316, 316L 318	A59 ER 316L	Low carbon 0.03% max., 18–20% Cr, 11–14% Ni, 2–3% Mo, for welding 18% Cr. 8% Ni, Mo and 18% Cr, 8% Ni, Mo, Nb types
316S96	316, 318		Carbon 0.08% max., 18–20% Cr, 11–14% Ni for steels of similar composition to give high impact strength at low temperatures
347S96	347, 321, 304		Carbon 0.08% max., 19–21.5% Cr, 9–11% Ni niobium stabilized. For steels of 20% Cr, 10% Ni type, giving high corrosion resistance
309S94	347		Carbon 0.12% max., 25% Cr, 12% Ni for welding mild and low-alloy steel to stainless steel. for buttering, when welding type 347 to mild steel and for temperatures up to 300°C

Note. Argon 1 or 2% oxygen is used as the shielding gas.
These wires are also used for submerged arc welding of stainless steels.
AISI: American Iron and Steel Institute.

Nickel alloys

The welding of nickel and nickel alloys can be done using spray transfer and short circuit (dip transfer) arc methods.

Spray transfer with its higher heat input gives high welding speeds and deposition rate and is used for thicker sections, usually downhand because of the large molten pool. Argon is used as the shielding gas but 10–20%

helium can be added for welding Nickel 200 and INCONEL® alloy 600, giving a wider and flatter bead with reduced penetration. The gun should be held as near to 90° to the work as possible, to preserve the efficiency of the gas shield, and the arc should be kept just long enough to prevent spatter yet not long enough to affect arc control.

Short circuiting arc conditions are used for thinner sections and positional welding, the lower heat input giving a more controllable molten pool and minimum dilution. The shielding gas is pure argon but the addition of helium gives a hotter arc and more wetting action so that the danger of cold laps is reduced. To further reduce this danger the gun should be held as near as possible to 90° to the work and moved so as to keep the arc on the plate and not on the pool. High-crowned profile welds increase the danger of cold laps.

The table in chapter 10 (p. 523) on TIG welding of nickel alloys indicates materials and filler metal suitable for welding by the MIG process and Fig.10.28 the recommended methods of preparation.

Aluminium alloys

When fabricating aluminium alloy sections and vessels, the plates and sections are cut and profiled using shears, cold saw, band saw or arc plasma and are bent and rolled as required and the edges cut to the necessary angle for welding where required. (*Note.* As the welding currents employed in the welding of aluminium are high, welding lenses of a deeper than normal shade should be used to ensure eye protection.)

The sections are degreased using a degreaser such as methyl chloride and are tack welded on the reverse side using either TIG or MIG so as to give as far as possible a penetration gap of close tolerance. Where this is excessive it can be filled using the TIG process, and pre-heating may be performed for drying. The areas to be welded are stainless steel wire brushed to remove all oxide and the root run is made. Each successive run is similarly wire brushed and any stop–start irregularities should be removed. It is important that the tack welds should be incorporated into the overbead completely so that there is no variation in it. Back-chipping of the root run, where required for a sealing run, should be performed with chisels, routers or saws and not ground, as this can introduce impurities into the weld.

Back-chipping and a sealing run add substantially to the cost of a welded seam. In many cases it can be avoided by correctly backpurging the seam and welding from one side only. Fig. 9.14 and table indicate typical butt weld preparation in the flat position using 1.6 mm filler wire. Fig. 9.15*a* shows the section of a MIG weld in aluminium and Fig. 9.15*b* a TIG weld on the preparation bead of Fig. 9.15*a*.

Plate thickness (mm)	Number of runs	Approximate current (A) Root	Subsequent	Root face (mm)
6 and 8	2	220	250–280	1.6
9.5 and 11	3	230	260–280	1.6
12.7 and 16	4	230–240	270–290	3.2
19	5	240–250	280–310	3.2
22 and 25	6	240–260	280–330	4.8

Refer also to BS 3571 *General recommendations for manual inert gas metal arc welding of aluminium and aluminium alloys.*
Suitable filler wires are given on p.517.

Fig. 9.14. Flat butt weld preparation, aluminium plate MIG, semi-automatic process argon shield Work negative

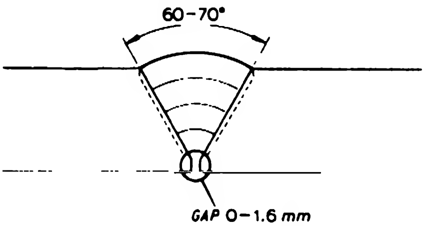
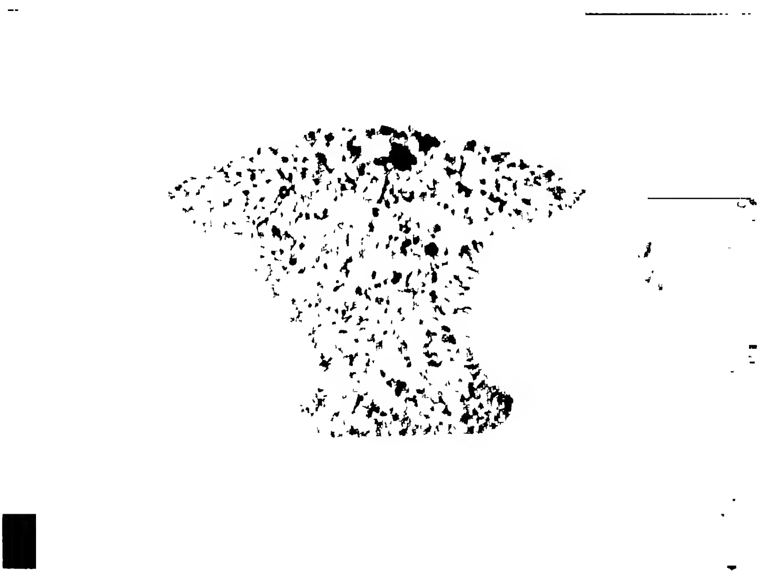


Fig. 9.15. (*a*) MIG weld in aluminium 5083 (NS8) plate 8 mm thick with 5556 A (NG61) wire Stainless steel backing bar.
1st run: 250–270 A, 26–27 V, speed 9–10 mm/second
2nd run: 260–280 A, 28–29 V, speed 8–10 mm/second
Preparation 90° V, 0–1 mm root gap, 3–4 mm root face



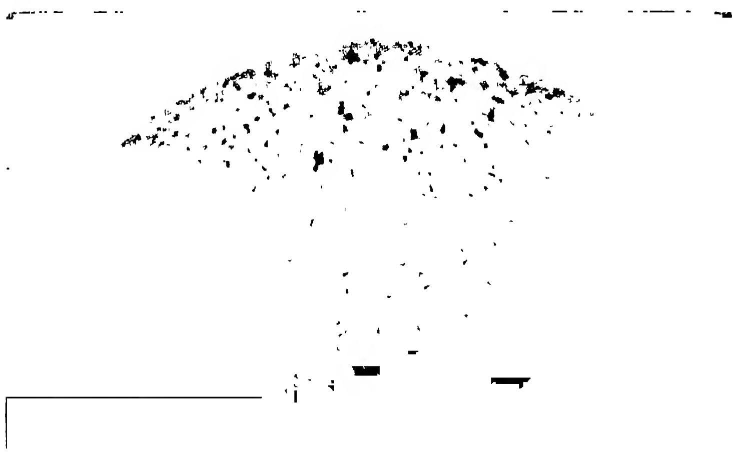
Copper and copper alloys

Many of the problems associated with the welding of copper and copper alloys are discussed in the chapter on the TIG process (**Chapter 10**) and apply equally to the MIG process. Because of the high thermal conductivity of copper and to reduce the amount of pre-heating, it is usual in all but the thinnest sections to use high currents with spray transfer conditions, which are obtainable with argon and argon- helium mixtures. The addition of nitrogen to argon destroys the spray transfer conditions but arc conditions are improved with up to 50% helium added to argon and this results in an increased heat output. For thin sections, fine feed wires can be used giving spray transfer conditions with lower current densities, thus preventing burn-through. **Fig. 9.16** shows edge preparation for TIG and MIG butt welds in copper.

SG cast irons

Pearlitic and ferritic cast irons are very satisfactorily welded using dip transfer conditions (e.g. 150 A, 22 V with 0.8 mm diameter wire) to give low heat input using filler wire of nickel or the NI-ROD* alloy range. Carbide precipitation in the HAZ is confined to thin envelopes around some of the spheroids, unlike the continuous film associated with MMA welding. SG iron can be welded to other metals and MONEL*, INCONEL* or INCO* alloys can be used to give a corrosion-resistant surface on SG iron castings or as a buffer layer for other weld deposits. See

Fig. 9.15. (*b*) TIG weld on penetration bead of the above weld. No back chipping, no filler wire (can be added if required) 350 A, 32 V, speed 3–4 mm second. Section etched with cupric chloride $CuCl_2$ followed by a 50% nitric acid wash.

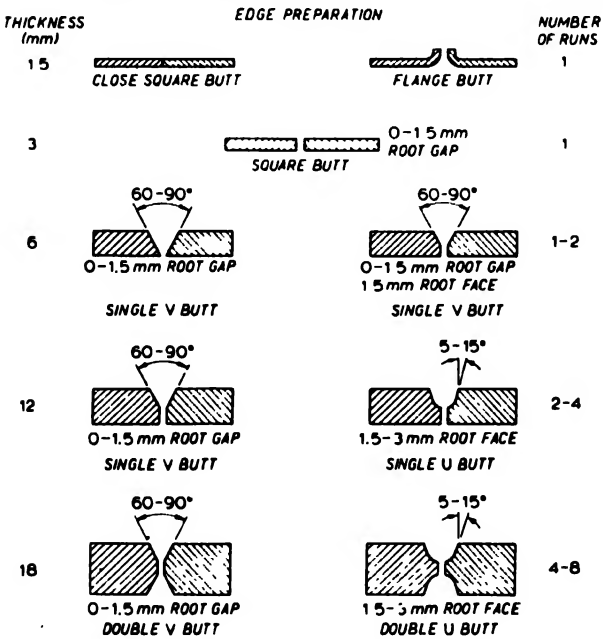


table, p.413. Cleaning and degreasing should be performed before welding, and pre-heat is only required for heavy pearlitic section or joints under heavy restraint when pre-heat of 200 °C is suitable. Minimum-heat input compatible with adequate fusion should always be used (Fig. 9.17).

MIG Process. Recommended filler wires for copper welding

Type (BS 2870–2875)	Grade	Filler wire: Argon or helium shield	Filler wire: Nitrogen shield
C106	Phosphorus deoxidized, non-arsenical	C7, C8, C21	Not recommended
C107	Phosphorus deoxidized, arsenical		
C101	Electrolytic tough pitch, high conductivity	C7, C8, C21	Not recommended
C102	Fire refined tough pitch, high conductivity		
C103	Oxygen-free, high conductivity	C7, C21	Not recommended

Fig. 9.16. Edge preparation for TIG and MIG butt welds in copper



CO_2 welding of mild steel

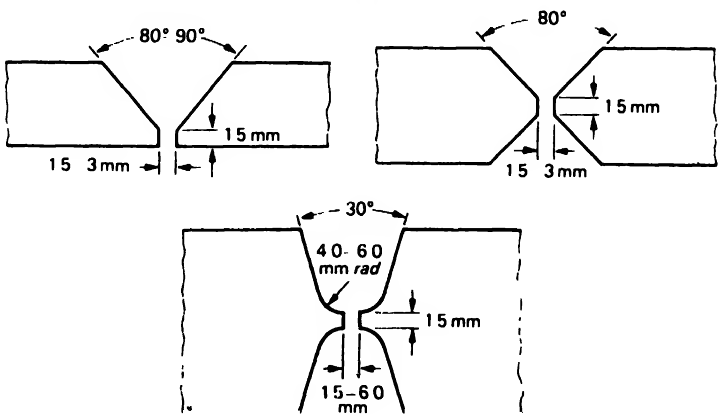
There are four controls to enable optimum welding conditions to be achieved: (1) wire feed speed which also controls the welding current, (2) voltage, (3) choke or series inductance and (4) gas flow.

For a given wire diameter the wire feed rate must be above a certain minimum value to obtain a droplet transfer rate of above about 20 per second, below which transfer is unsatisfactory. With increasing wire feed rate the droplet transfer rate and hence the burn-off increases and the upper limit is usually determined by the capacity of the wire feed unit. The voltage setting also affects the droplet frequency rate and determines the type of transfer, about 15–20 V for short-circuit or dip, and 27–45 V for spray, with an intermediate lesser used zone of about 22–27 V for the semi-short-circuiting arc.

The choke, which limits the rate of current rise and decay, is also important because too low a value can give a noisy arc with much spatter and poor weld profile, while too high a value can give unstable arc conditions with more difficult start and even occasional arc extinguishing. Between these limits there is a value which with correct arc voltage and wire feed rate gives a smooth arc with minimum spatter and good weld profile. Penetration is also affected by the choke value, **see p. 223.**

As stated before, the short-circuiting arc is generally used for welding thinner sections, positional welding, tacking and on thicknesses up to 6.5 mm. In positional welding the root run may be made downwards with no weave and subsequent runs upward. The lower heat output of this type of arc reduces distortion on fabrications in thinner sections and minimizes

Fig. 9.17. Preparation for welding of SG cast irons.



over-penetration. The spray-type arc is used for flat welding of thicker sections and gives high deposition rates.

Gas flow rate can greatly affect the quality of the weld. Too low a flow rate gives inadequate gas shielding and leads to the inclusion of oxides and nitrides, while too high a rate can introduce a turbulent flow of the CO_2 which occurs at a lower rate than with argon. This affects the efficiency of the shield and leads to a porosity in the weld. The aim should be to achieve an even non-turbulent flow and for this reason spatter should not be allowed to accumulate on the nozzle, which should be directed as nearly as possible at 90° to the weld, again to avoid turbulence.

The torch angle is, in practice, about 70–80° to the line of travel consistent with good visibility and the nozzle is held about 10–18 mm from the work. If the torch is held too close, excess spatter build-up necessitates frequent cleaning, and in deep U or V preparation the angle can be increased to obtain better access. Weaving is generally kept as low as convenient to preserve the efficiency of the gas shield and reduce the tendency to porosity. Wide weld beads can be made up of narrower 'stringer' runs, and tilted fillets compared with HV fillets give equal leg length more easily, with better profile.

Mild steel sheet, butt welds, CO_2 shielding, flat, 0.8 mm diam. wire (approximate values)

Thickness (mm)	Gap (mm)	Wire feed (m/minute)	Arc (volts)	Current (A)
1	0	2.8–3.8	16–17	65–80
1.2	0	3.2–4.0	18–19	70–85
1.6	0.5	4.0–4.8	19–20	85–95
2.0	0.8	5.8–7.0	19–20	110–125
2.5	0.8	7.0–8.4	20–21	125–140
3.0	1.5	7.0–8.4	20–21	125–140

Economic considerations

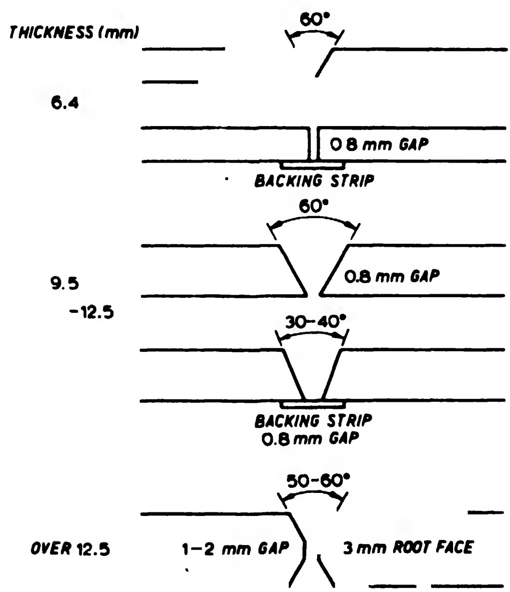
Although filler wire for the CO_2 process, together with the cost of the shielding gas, is more expensive than conventional electrodes, other factors greatly affect the economic viability of the process. The deposition rate governs the welding speed which in turn governs the labour charge on a given fabrication.

The deposition rate of the filler metal is a direct function of the welding current. With metal arc welding the upper limit is governed by the

overheating of the electrode. The current I amperes flows through the electrode, the wire of which has an electrical resistance R ohms, so that the heating effect is $\propto I^2R$. The resistance of any metallic conductor increases with the rise in temperature, so that, as the electrode becomes hotter, the resistance and hence the I^2R loss increases so that with excessive currents, when half of the electrode has been consumed, the remaining half has become red hot and the coating ruined. Iron powder electrodes have a greater current-carrying capacity due to the conductivity of the coating, the electrical resistance being reduced. With the CO_2 process the distance from contact tube to wire tip is of the order of 20 mm so that the electrical resistance is greatly reduced even though the wire diameter is smaller. The current can thus be increased greatly, resulting in higher deposition rates, greater welding speeds and reduced labour charges. In addition the duty cycle is increased since there is no constant electrode change and need for deslagging, but there may be greater spatter loss. Economically therefore the CO_2 process shows an advantage in very many applications, though the final choice of process is governed by the application and working conditions.

By using the argon–CO_2 gas mixtures, certain advantages are obtained over CO_2 which may offset the greater price of the mixtures. These are faster welding speed and reduced spatter, with an improved weld profile.

Fig. 9.18. Various preparations for thicker plate (varying with applications). CO_2 welding.



When welding thin steel sections with a dip transfer arc, argon–CO_2 mixtures are often preferred because there is a lower voltage drop across the arc which thus gives a cooler molten pool and prevents burn-through, especially if the fit-up is poor.

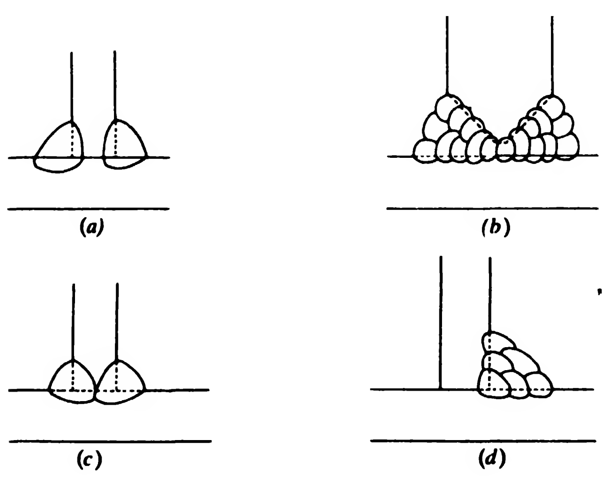
Details of plate preparation are given as a guide only, since there are too many variables to give generalized recommendations (see Figs. 9.18 and 9.19).

Automatic welding

Automatic welding, by MIG, pulse and CO_2 processes, now plays an important part in welding fabrication practice. It enables welds of consistently high quality and accuracy to radiographic standard to be performed at high welding speeds because of the close degree of control over the rate of travel and nozzle-to-work distance. It is less tolerant than semi-automatic welding to variations of root gap and fit-up but reduces the number of start–stop breaks in long sequences. The choice between semi-automatic and automatic process becomes a question of economics, involving the length of runs, number involved, volume of deposited metal if the sections are thick, method of mechanization and set-up time. The torches are now usually air cooled even for currents up to 450 A and are carried on welding heads fitted with controls similar to those used for semi-automatic welding, and may be remote controlled (Fig. 9.20).

The head may be: (1) fixed, with the work arranged to move or be rotated beneath it, (2) mounted on a boom and column which can either be of the

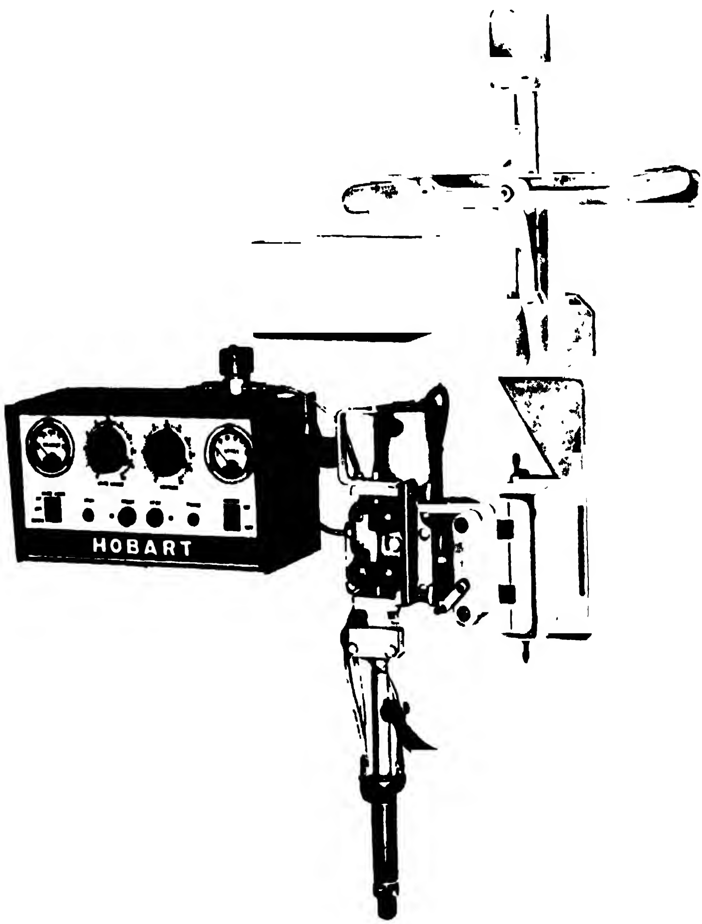
Fig. 9.19. (*a*) Unprepared fillets. (*b*) multi-run prepared fillets in thick plate, (*c*) deep preparation fillets, (*d*) multi-run unprepared fillet CO_2 welding



positioning type in which the work moves, or the boom can traverse over the work (**Figs. 9.21*a* and *b***), (3) gantry mounted so as to traverse over the stationary work, (4) tractor mounted, running on guide rails to move over the fixed work, (5) mounted on a special machine or fixture designed for a specific production. A head may carry two torches arranged to weld simultaneously, thus greatly reducing the welding time.

For the CO_2 process in steel a typical example would be with wire of 1.2 mm diameter using 150-170 A on thinner sections and multiple passes up to 30 on thicknesses up to 75 mm with current in the 400–500 A range and 2.4 mm wire. With automatic surge (pulse) arc welding on stainless

Fig. 9.20. MIG head showing wire feed



steel, accurate control of the underbead is achieved, obviating the necessity for back-chipping and sealing run. In the case of aluminium welding on plate above 10 mm thickness the accuracy of the underbead produced with the MIG automatic process results in more economical welding than by the double-operator vertical TIG method. In general the full automation of these processes results in greater productivity with high-quality welds.

Magnetic arc control systems

Magnetic probes with electronic solid state control and with water cooling if required can be fitted onto or near to the welding head and are applicable to spray, MIG, TIG, plasma and submerged arc systems **(Fig. 9.22*a* and *b*).**

Fig. 9.21. (*a*) A ram-type boom with welding head

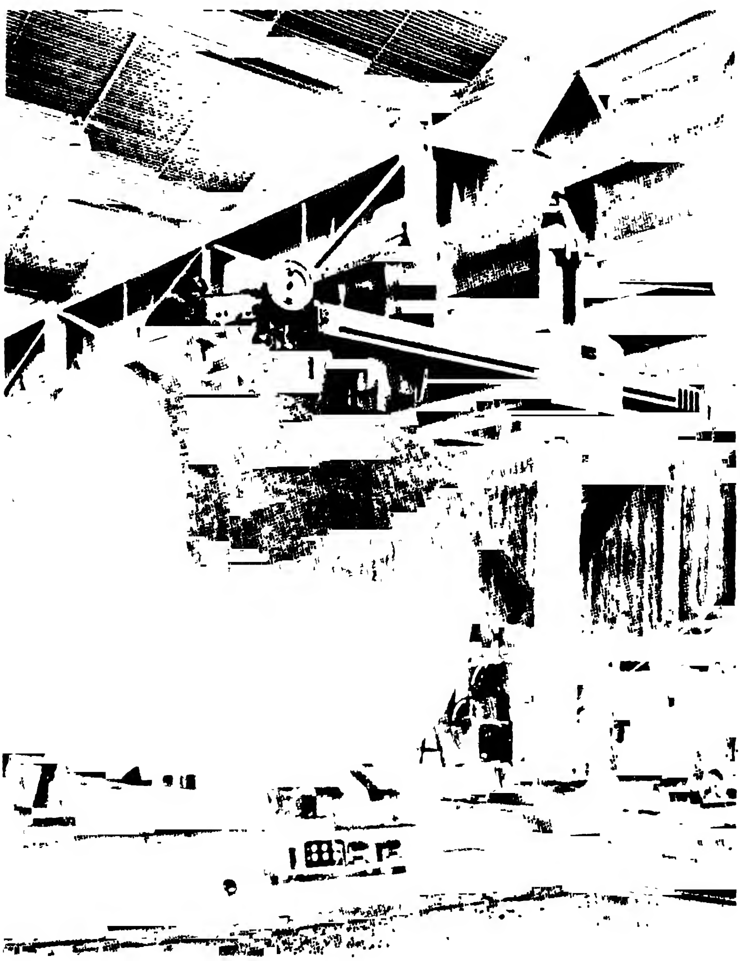


Fig. 9.21. (*b*) Extra heavy duty column and boom and roller bed.

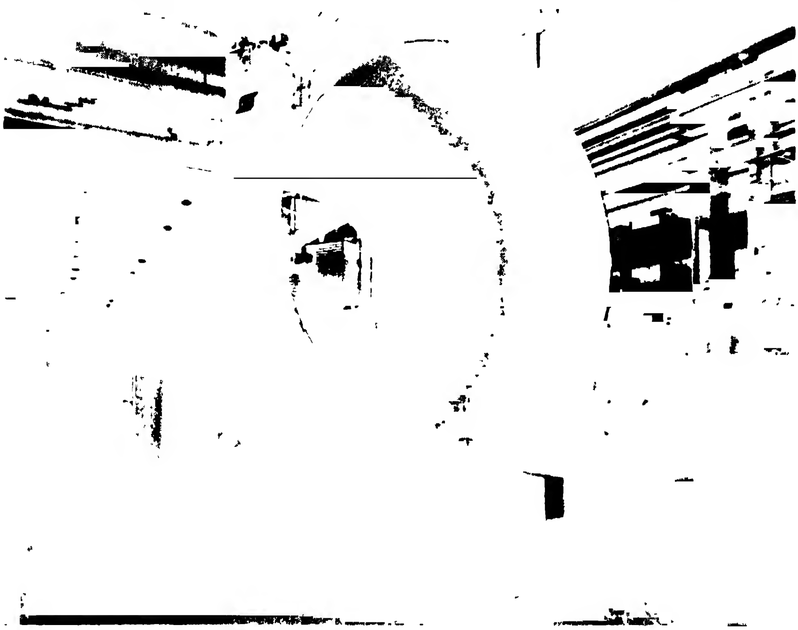
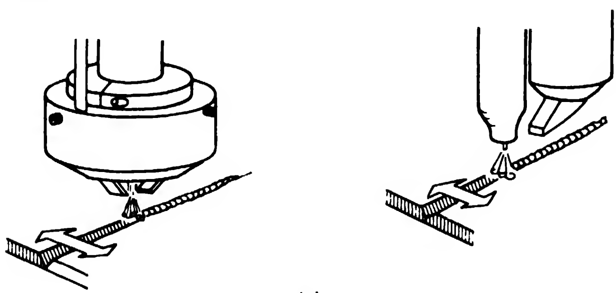
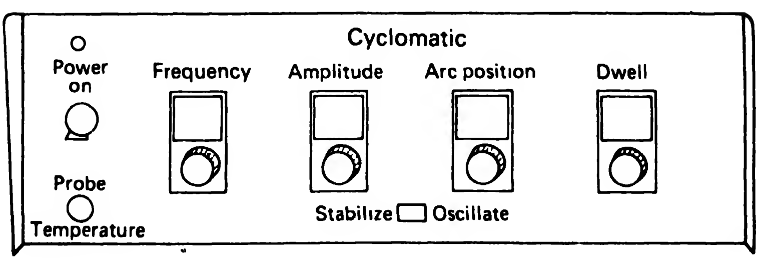


Fig. 9.22. (*a*) Types of probe (*b*) Magnetic arc control



(*a*)



(*b*)

The arc can be stabilized or oscillated by the applied magnetic field and magnetic and non-magnetic materials are equally well welded when using this system. Controls on the unit enable the sweep frequency to be varied from 0 to 100 oscillations per second while sweep amplitude and arc position are controllable and proportional to the arc length in an approximately 1:1 ratio. There is controllable variable dwell on each side of the oscillation in order to obtain good fusion, arc blow is counteracted and the heat imput can be balanced when welding thin to thick sections, and undercut is minimized. Porosity is decreased and the system is applicable, for example, to the welding of thicker stainless steel sections resulting in reduced danger from cracking, reduced porosity and greater weld reliability. This method of arc stabilization and control is now becoming increasingly popular as MIG and submerged arc welding become more automated.

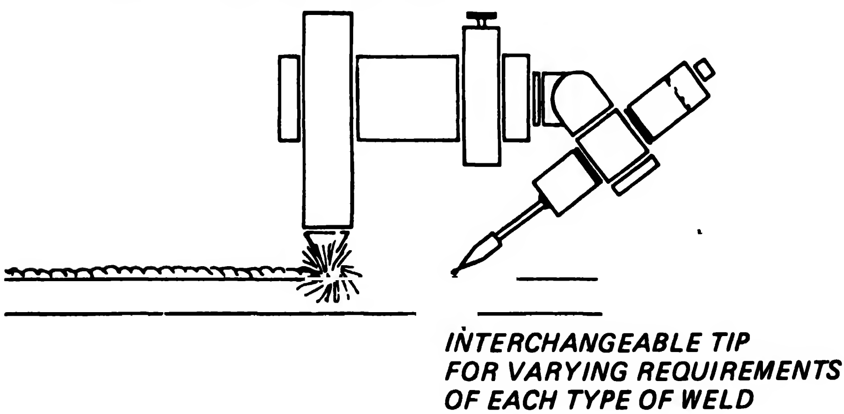
Seam tracker

This unit bolts on to the head of the welding torch and enables the torch to follow accurately the line of the joint to be welded.

The torch head is placed over the seam or joint and the tracker keeps the arc over the seam with an accuracy of less than 0.25 mm.

One type has an electro-mechanical sensor which responds to the movement of the probe tip which moves along the seam. The signals are sent by the probe to the solid state control which operates two linear slides whose axes are at right angles to each other, one horizontal and the other vertical. These are driven by small d.c. motors and keep the welding head in place exactly over the seam to be welded, which keeps the torch-to-work distance constant (Fig. 9.23).

Fig. 9.23. Programmable seam tracker.



The optical seam tracker using flexible fibre optics for operation and with microcircuit control operating the cross slides as in the previous unit keeps the torch head accurately over the joint, which should be a tight machined edge butt weld, although this system can tolerate a gap of 2 mm and still keep the torch central to the joint.

MIG spot welding

Spot welding with this process needs access to the joint on one side only and consists of a MIG weld, held in one spot only, for a controlled period of time. Modified nozzles are fitted to the gun, the contact tip being set 8–12 mm inside the nozzle, and the timing unit can either be built into the power unit or fitted externally, in which case an on–off switch does away with the necessity of disconnecting the unit when it is required for continuous welding. The timer controls the arcing time, and welds can be made in ferrous material with full or partial penetration as required. A typical application of a smaller unit is that of welding thin sheet as used on car bodies. The spot welding equipment timer is built into a MIG unit and is selected by a switch. Wire of 0.6 mm diameter is used with argon + CO_2 5% + O_2 2% as the shielding gas. Currents of 40–100 A are available at 14–17 V for continuous welding with a maximum duty cycle of 60%. The spot welding control gives a maximum current of 160 A at 27 V, enabling spot welds to be made in material down to 0.5 mm thickness, the timing control varying from 0.5–2.0 seconds.

On larger units arcing time can be controlled from 0.3 to 4.5 seconds with selected heavier currents enabling full penetration to be achieved on ferrous plate from 0.7 to 2.0 mm thick and up to 2.5 mm sheet can be welded on to plate of any thickness.

Cycle arc welding is similar to spot welding except that the cycle keeps on repeating itself automatically as long as the gun switch is pressed. The duration of the pause between welds is constant at about 0.35 seconds while the weld time can be varied from 0.1 to 1.5 seconds. This process is used for welding light-section components which are prone to burn-through. In the pause between the welding period, the molten pool cools and just solidifies, thus giving more accurate control over the molten metal.

MIG pulsed arc welding

Pulsed arc welding is a modified form of spray transfer in which there is a controlled and periodic melting off of the droplets followed by projection across the arc. A pulse of voltage is applied for a brief duration

at regular frequency and thus results in a lower heat output than with pure spray transfer, yet greater than that with dip transfer. Because of this, thinner sections can be welded than with spray transfer and there is no danger of poor fusion in a root run as sometimes occurs with dip transfer and positional welding is performed much more easily. There is regular and even penetration, no spatter and the welds are of high quality and appearance.

To obtain these conditions of transfer it is necessary to have two currents fed to the arc: (*a*) a background current which keeps the gap ionized and maintains the arc and (*b*) the pulsed current which is applied at 50 or 100 Hz and which melts off the wire tip into a droplet which is then projected across the arc gap. These two currents, which have critical values if satisfactory welding conditions are to be obtained, are supplied from two sources, a background source and a pulse source contained in one unit, and their voltages are selected separately. The background current, of much lower value than the pulse, is half a cycle out of phase with it (see **Figs. 9.24*a*** and *b*). A switch enables the pulse source to be used for dip and spray transfer methods as required. The power supply is a silicon rectifier with constant voltage output and a maximum current value of about 350 A at open-circuit voltages of 11–45 V similar to those already described.

To operate the unit, the 'pulse height' (the value of pulse current) and the background current are selected on separate switches, the wire is adjusted to protrude about 10 mm beyond the nozzle and welding is commenced

Fig. 9.24 (*a*) Wave shape of pulse supply

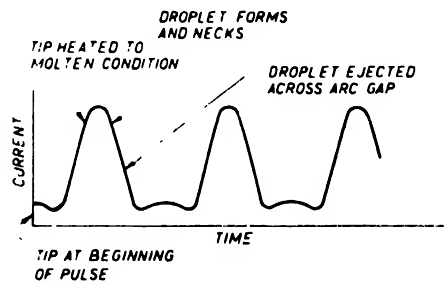
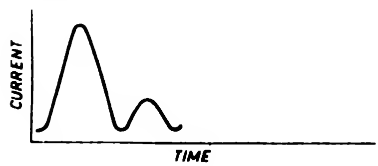


Fig. 9.24. (*b*) Modified pulse supply with background pulse

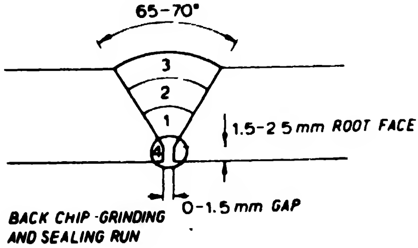


moving from right to left down the line of the weld with the gun making an angle of 60–70° with the line of weld. When welding fillets the gun is usually held at right angles to the line of weld with the wire pointing directly into the joint, and thus an excellent view is obtained of the degree of fusion into the root; welding is again performed from right to left. The process gives good root fusion with even penetration and good fill-in and is especially efficient when used fully automatically. As in all other welding processes, welding is best performed flat but positional welding with pulsed arc is very satisfactory and relatively easy to perform. Thicknesses between 2 mm and 6.5 mm which fall intermediate in the ranges for dip and spray transfer are easily welded. One of the drawbacks to pulse arc is the necessity to ensure accurate fit-up. If there are any sizeable gaps a keyhole effect is produced and it is impossible to obtain a regular underbead. The gap should be of the order of from 0 to about 1.0 mm max. The shielding gas is argon with 1% or 2% oxygen or argon with 5% CO_2 and 2% oxygen for welding mild and low-alloy steels, stainless steel and heat-resistant steel, and pure argon for aluminium and its alloys, 9% nickel steel and nickel alloys. Pulse arc is especially useful when used automatically for stainless steel welding, since the accurately formed under- or penetration bead obviates the expensive operation of back-chipping and a sealing run and there is little carbon pick-up and thus little increase of carbon content in the weld. Aluminium requires no back purge and for the back purge on stainless steel a thin strip of plate can be tack welded on the underside of the joint (see Fig. 9.13) and removed after welding. The argon from the torch supplies the back purge and prevents oxidation of the underside of the weld.

There is good alloy recovery when welding alloy steel and because of the accurate heat control, welding in aluminium is consistently good without porosity and a regular underbead so that it can be used in place of double argon TIG with a saving of time and cost.

Fabrications and vessels can be fully tack weld fabricated with TIG on the underside of the seam and pulse arc welded, greatly reducing the

Fig. 9.25. Automatic pulsed arc welding of stainless steel, flat, 99% argon-1% oxygen.



tendency to distortion. The torch should be held at 75–80° to the line of the weld and good results are also obtained fully automatically by welding from left to right with the torch held vertically to the seam. This method allows greater tolerance in fit-up and preparation with better penetration control. Because this process is sensitive to the accuracy of fit-up and preparation, care should be taken to work to close tolerances and excessive gaps should be made up from the reverse side with, for example, the TIG process, and then carefully cleaned.

Fig. 9.25 and the table give a typical preparation for automatic flat butt welds in stainless steel using 99% A, 1% O_2 as shielding gas and 1.6 mm diameter filler wire. For the alloys of nickel the recommended shielding gas is pure argon. A similar technique is used as for the MIG welding of stainless steel, with a slight pause each side of the weave to avoid undercut.

Plate thickness (mm)	Runs	Current (A) Roots and subsequent	Volts (approx.)
4.8, 6.4, 8	2	180 200	27-28
9.5	3	180 210	27-28

There appears to be no advantage in using the pulse method over the normal shielded metal arc with unpulsed wave when using CO_2 as the shielding gas. (See Appendix 13.)

Synergic pulse MIG welding

In the first generation of pulsed MIG units the output waveform consisted essentially of a half or full wave rectified sine wave (pp. 480–1) with the pulse frequency fixed by that of the main supply to either 50 or 100 Hz (UK), see Figs 9.24*a*, *b* and 9.26*a*.

In order to establish the welding condition the operator was required to set four variables, namely peak current or voltage, pulse frequency, background current and wire feed speed. Hence, although pulse MIG was found to have significant benefits for many applications, especially aluminium and stainless steel, the complex nature of the process and high degree of skill required to establish the correct welding parameters, heavily limited its acceptance by the welding industry. Common complaints regarding the process included variation in transfer with 'stick out', narrow operating range for a given consumable, undercut and spatter. It is clear with these original units that the quantity of metal detached per pulse was directly related to wire feed speed (Fig. 9.26*b*).

Research work during the late 60s and early 70s had demonstrated that for each wire diameter/material combination there is a specific droplet size for optimum metal transfer. In fact, the diameter of this droplet is very nearly equal to the wire diameter. Further, for each wire, specific pulse parameters, i.e. peak current and pulse width, can be defined to detach such a droplet.

With the advent of electronically controlled and transistorized power sources, it became possible to generate wave shapes that were rectangular instead of sinusoidal (Fig. 9.26*c*). Equally, since the output was no longer synchronized to mains frequency, the pulse frequency could now be varied from well below 50 Hz to in excess of 300 Hz and functions like

Fig. 9.26(*a*)

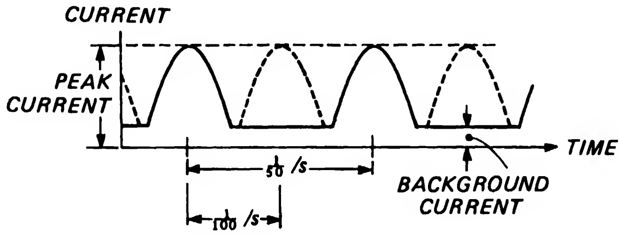


Fig. 9.26(*b*)

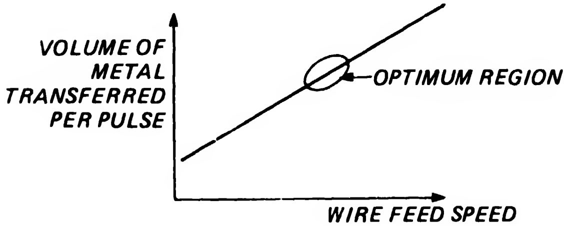
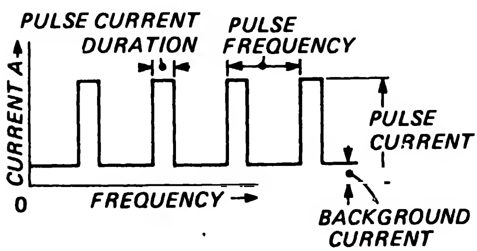


Fig. 9.26(*c*)

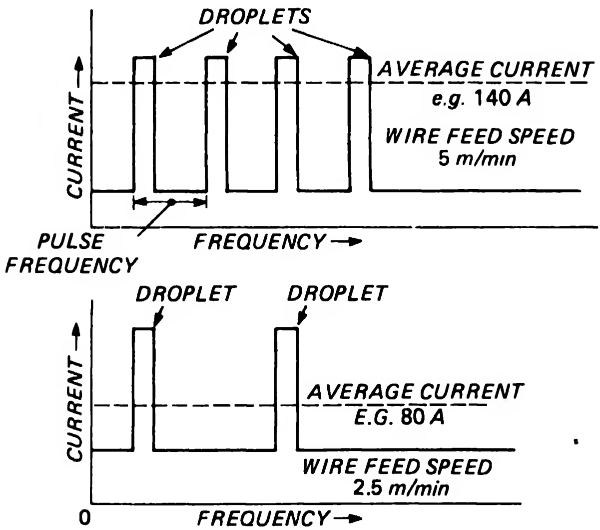


output volt ampère relationships and pulse waveform could be accurately predicted and controlled. See also p. 502.

In the synergic (Gr. *syn*, together; *ergon*, work) pulse MIG process, the correct pulse parameters are selected, usually automatically, depending upon the wire diameter, material and shielding gas combination chosen. The pulse frequency and wire feed speed are electronically linked together so that as the wire speed is increased so the pulse frequency is increased and vice versa. A stream of droplets of constant size are transferred, one per pulse, with the transfer frequency linked directly to the wire feed speed and hence the average current demand (Fig. 9.26*d*). As a result, the operator is relieved of the onus of establishing the various parameters each time that the work is changed. When the torch switch is pressed, the average current demand set by the one-knob control is automatically translated into wire speed and pulse frequency information, the actual value of pulse frequency depending on the wire diameter selected. The correct value of inductance is also 'electronic' so that no inductance 'tappings' are required.

The pulsed current gives a projected spray type open-arc transfer over a wide range of currents and, in particular, at levels far below the normal dip-to-spray transition. This has the benefit of offering an all-positional

Fig. 9.26(*d*)

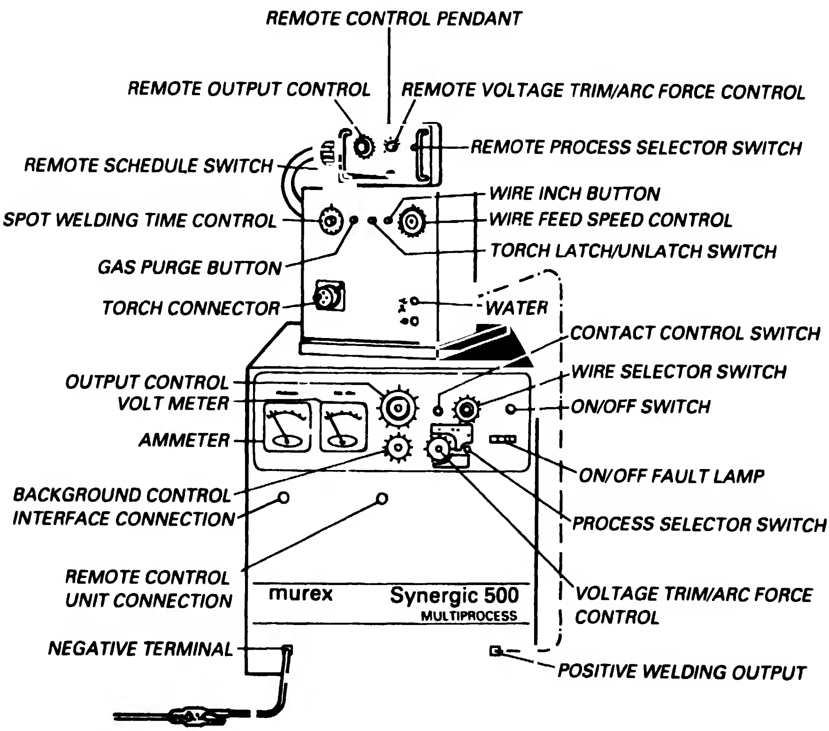


PULSE FREQUENCY AND WIRE FEED RELATIONSHIP
INCREASE OF WIRE FEED (AVERAGE CURRENT) GIVES INCREASE OF PULSE FREQUENCY.

welding method with virtually no spatter, and the regularity of actual transfer of the droplet gives a smooth stable weld pool.

Most synergic machines offer the ability to run a wide range of wires including mild and stainless steels in synergic mode. Some models can operate in all three process modes (dip, pulse and spray transfer) with various shielding gases, using the one-knob control system. Most have an

Fig. 9.26. (*e*) Synergic 500 for MMA, TIG and MIG processes with dip/spray or pulse modes. Input 3-phase 380–415 V. Adjustment of background current for pulse MIG. KVA input 34. Auxiliary power 1 A at 220 V and 4 A at 42 V Voltage trim/arc force controls permits arc length/arc voltage to be adjusted. Remote control if required. Inch button. Pulsed arc is very suitable for plate 2–6 mm thick, and gives good results on stainless steel with good alloy, recovers on alloy steels. Used with pure argon it is very suitable for aluminium welding. (See Appendix 13, p. 774, for photograph of unit.)

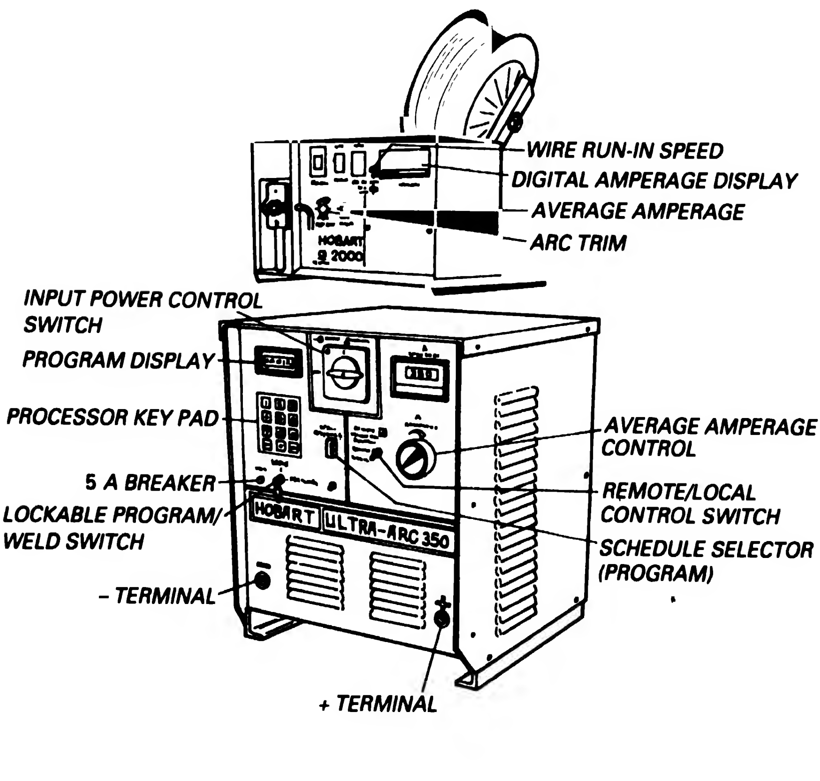


arc voltage trim function enabling the operator to adjust the arc length to suit specific needs.

Two such modern synergic units are shown in Figs 9.26*e* and 9.26*f*.

Plasma MIG process. A process is being developed in which MIG filler wire is fed through a contact tube situated centrally in the torch head. A tungsten electrode is set at an angle to this contact tube and projects nearly to the mouth of the shielding nozzle through which the plasma gas issues. An outer nozzle provides a gas shield. The current through the wire assists

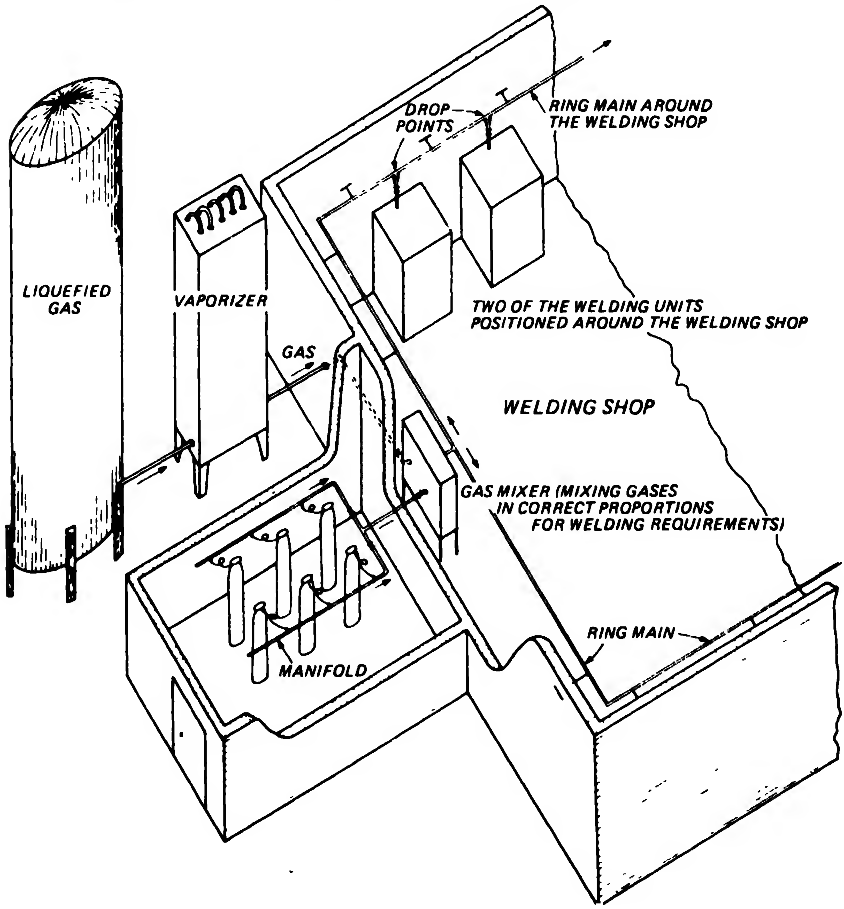
Fig. 9.26. (*f*) Ultra-arc 350 synergic transistorized pulsed MIG. Spray transfer one-knob synergic control of five parameters: pulse current, pulse time, background current, pulse frequency and wire feed speed. Input 200, 230 or 460 V 3-phase. Single current control 50–350 A. Constant energy CC and CV which reduces shrinkages and distortion. The constant energy is irrespective of the stick out and makes welding of difficult ferrous metals easier, smooth arc. Micro processor control has nine preset programs e.g. mild steel of two sizes using 95% Ar, 5% CO_2; stainless steel of three sizes using 98% Ar, 2% O_2; silicon bronze of two sizes using 100% Ar; and aluminium of two sizes using 100% Ar. (See Appendix 13, p. 775, for photograph of plant.)



the melting and gives good starting characteristics and a stable arc, so that thin plate is weldable at high welding speeds.

Repair of cast iron by automated MIG process using tubular electrodes. With the advent of flux cored wire (9.10*a*) carbon can be added to the core and high speed welding performed using high nickel iron wire. As an example, nickel FC 55 is a tubular wire, the core being filled with carbon, slagging constituents and deoxidizers. It can be used with or without a shielding gas such as CO_2 and no post-weld heat treatment is required. Standard gas-metal arc equipment is used, the joints have high strength and the HAZ is free from the carbide complex which can cause embrittlement. It makes possible the automatic welding of cast irons to themselves or to stainless steel or high nickel alloys and can be used for overlaying and metal arc spot welding.

Fig. 9.27. Gas mixing system for mixing shielding gases.



Liquid (gas) storage and gas mixing systems

The gas mixer (Fig. 9.27) mixes the gases in proportions suitable for welding. The proportion of each gas can be adjusted and the panel maintains this proportion over a wide range of flow requirements. A typical example is the mixing of argon and carbon dioxide as in the Coogar or Argoshield range (see Appendix 6).

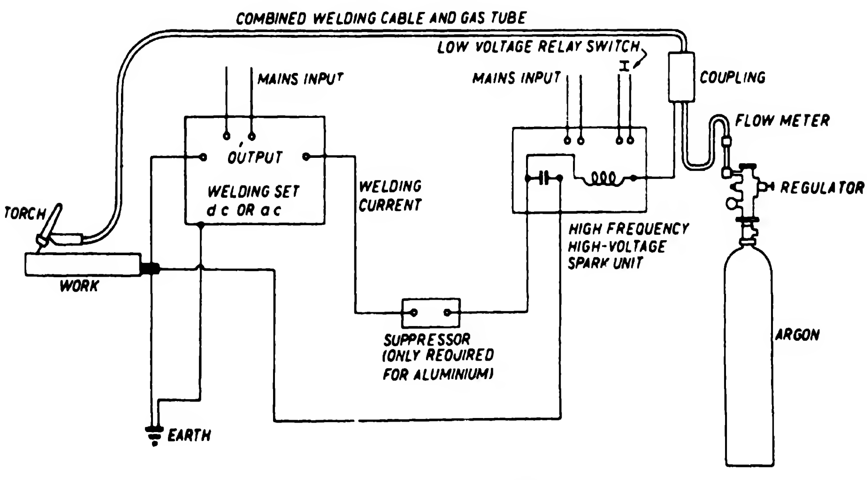
10

*Tungsten electrode, inert gas shielded welding processes (TIG), and the plasma arc process**

Technology and equipment

The welding of aluminium and magnesium alloys by the oxy-acetylene and manual metal arc processes is limited by the necessity to use a corrosive flux. The gas shielded, tungsten arc process (Fig.10.1) enables these metals and a wide range of ferrous alloys to be welded without the use of the flux. The choice of either a.c. or d.c. depends upon the metal to be welded. for metals having refractory surface oxides such as aluminium and its alloys, magnesium alloys and aluminium bronze, a.c. is used whilst d.c. is used for carbon and alloy steels, heat-resistant and stainless steels, copper and its alloys, nickel and its alloys, titanium, zirconium and silver.

Fig. 10.1. Connexions for inert gas welding using air-cooled torch.



* American designation gas tungsten arc welding (GTAW)
See also BS 3019 TIG welding, Parts 1 and 2.

(See also BS 3019, *General recommendations for manual inert gas tungsten arc welding*. Part 1, *Wrought aluminium, aluminium alloys and magnesium alloys*; Part 2, *Austenitic stainless and heat resisting steels*.)

The arc burns between a tungsten electrode and the workpiece within a shield of the inert gas argon, which excludes the atmosphere and prevents contamination of electrode and molten metal. The hot tungsten arc ionizes argon atoms within the shield to form a gas plasma consisting of almost equal numbers of free electrons and positive ions. Unlike the electrode in the manual metal arc process, the tungsten is not transferred to the work and evaporates very slowly, being classed as 'non-consumable'. Small amounts of other elements are added to the tungsten to improve electron emission. It is, however, a relatively slow method of welding.

Gases

Argon in its commercial purity state (99.996%) is used for metals named above, but for titanium extreme purity is required. Argon with 5% hydrogen gives increased welding speed and/or penetration in the welding of stainless steel and nickel alloys; nitrogen can be used for copper welding on deoxidized coppers only. Helium may be used for aluminium and its alloys and copper, but it is more expensive than argon and, due to its lower density, a greater volume is required than with argon to ensure adequate shielding, and small variations in arc length cause greater changes in weld conditions. A mixture of 30% helium and 70% argon is now used, and gives fast welding speeds. The mechanized d.c. welding of aluminium with helium gives deep penetration and high speeds.

The characteristics of the arc are changed considerably with change of direction of flow of current, that is with arc polarity.

Electrode positive

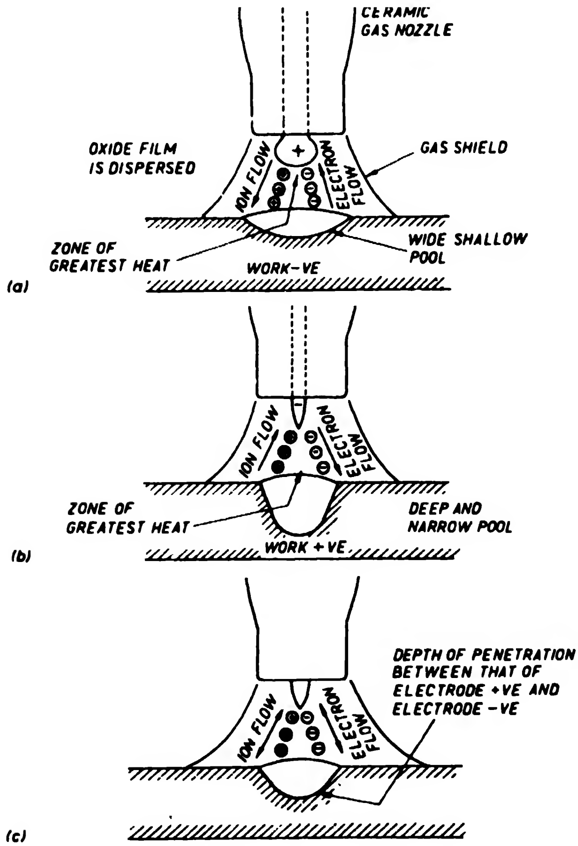
The electron stream is from work to electrode while the heavier positive ions travel from electrode to work-piece (Fig. 10.2*a*). If the work is of aluminium or magnesium alloys there is always a thin layer of refractory oxide of melting point about 2000 °C present over the surface and which has to be dispersed in other processes by means of a corrosive flux to ensure weldability. The positive ions in the TIG arc bombard this oxide and, together with the electron emission from the plate, break up and disperse the oxide film. It is this characteristic which has made the process so successful for the welding of the light alloys. The electrons streaming to the tungsten electrode generate great heat, so its diameter must be relatively large and it forms a bulbous end. It is this overheating with consequent vaporization of the tungsten and the possibility of tungsten being

transferred to the molten pool (pick-up) and contaminating it that is the drawback to the use of the process with electrode positive. Very much less heat is generated at the molten pool and this is therefore wide and shallow.

Electrode negative

The electron stream is now from electrode to work with the zone of greatest heat concentrated in the workpiece so that penetration is deep and the pool is narrower. The ion flow is from work to electrode so that there is no dispersal of oxide film and this polarity cannot be used for welding the light alloys. The electrode is now near the zone of lesser heat and needs be of reduced diameter compared with that with positive polarity. For a given diameter the electrode, when negative, will carry from four to eight times

Fig. 10.2. Electron streams between electrode and work: (*a*) d.c., tungsten electrode +ve of large diameter tends to overheat, (*b*) d.c., tungsten electrode −ve of small diameter; (*c*) a.c., electrode diameter between that of electrode +ve and −ve electrode.



the current than when it is positive and twice as much as when a.c. is used. (Fig. 10.2*b*).

Alternating current

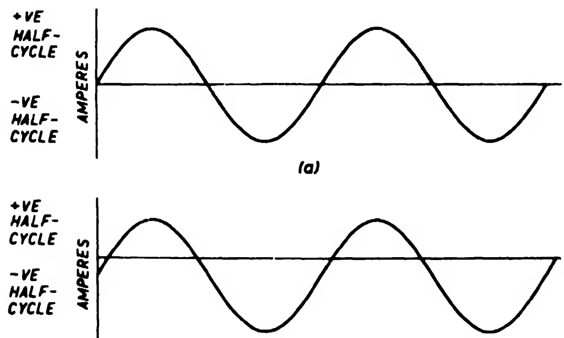
When a.c. is used on a 50 Hz supply, voltage and current are reversing direction 100 times a second so that there is a state of affairs between that of electrode positive and electrode negative, the heat being fairly evenly distributed between electrode and work (Fig. 10.2*c*). Depth of penetration is between that of electrode positive and electrode negative and the electrode diameter is between the previous diameters. When the electrode is positive it is termed the positive half-cycle and when negative the negative half-cycle. Oxide removal takes place on the positive half-cycle.

See note on square wave equipment and wave balance control (pp. 502–5).

Inherent rectification in the a.c. arc

In the a.c. arc the current in the positive half-cycle is less than that in the negative half-cycle (Fig. 10.3*b*). This is known as inherent rectification and is a characteristic of arcs between dissimilar metals such as tungsten and aluminium. It is due to the layer of oxide acting as a barrier layer to the current flowing in one direction and to the greater emission of electrons from the tungsten electrode when it is of negative polarity. The result of this imbalance is that an excess pulsating current flows in one direction only and the unbalanced wave can be considered as a balanced a.c. wave, plus an excess pulsating current flowing in one direction only on the negative half-cycle. This latter is known as the d.c. component and can be measured with

Fig.10.3. Alternating current. (*a*) balanced wave; (*b*) unbalanced wave, inherent rectification (current in +ve half-cycle less than that in −ve half cycle).



a d.c. ammeter. (The suppression of this d.c. component is discussed later.) The reduction of current in the positive half-cycle due to the inherent rectification results in a reduction of oxide removal.

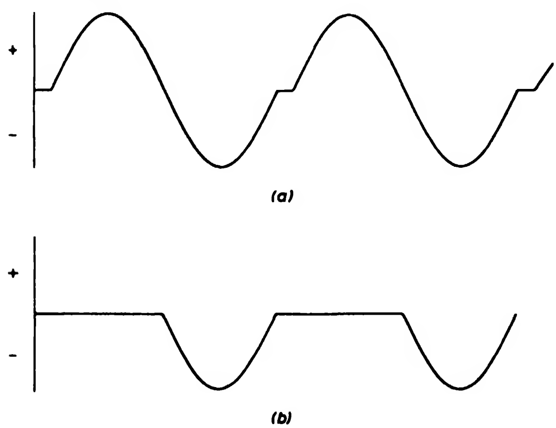
Partial rectification

A greater voltage is required to strike the arc than to maintain it and re-ignition on the negative half-cycle requires a lower voltage than for the positive half-cycle, partly due to the greater electron emission from the tungsten when it is negative polarity, but actual re-ignition depends upon many factors including the surface condition of the weld pool and electrode, the temperature of the pool and the type of shielding gas. There may be a delay in an arc re-ignition on the positive half-cycle until sufficient voltage is available and this will result in a short period of zero current (Fig. 10.4*a*) until the arc ignites. This delay reduces the current in the positive half-cycle and this state is known as partial rectification. If the available voltage is not sufficient, ignition of the arc may not occur at all on the positive half-cycle, the arc is extinguished on the one half-pulse and continues burning on the uni-directional pulses of the negative half-cycle, and we have complete rectification with gradual extinguishing of the arc (Fig. 10.4*b*).

Re-ignition voltages

To ensure re-ignition of the arc on the positive half-cycle, the available voltage should be of the order of 150 V, which is greater than that of the supply transformer. To ensure re-ignition, auxiliary devices are used which obviate the need for high open-circuit transformer voltages.

Fig. 10.4. (*a*) Partial rectification, (*b*) half-wave rectification (+ve half-cycle missing).



Ignition and re-ignition equipment*

High-frequency, high-voltage, spark gap oscillator. This device enables the arc to be ignited without touching down the electrode on the work and thus it prevents electrode contamination. It also helps arc re-ignition at the beginning of the positive half-cycle.

The oscillator consists of an iron-cored transformer with a high voltage secondary winding, a capacitor, a spark gap and an air core transformer or inductive circuit, one coil of which is in the high voltage circuit and the other in the welding circuit (Fig. 10.5). The capacitor is charged every half cycle to 3000–5000 V and discharges across the spark gap. The discharge is oscillatory, that is, it is not a single spark but a series of sparks oscillating across the spark gap during discharge. This discharge, occurring on every half-cycle, sets up oscillatory currents in the circuit and these are induced and superimposed on the welding current through the inductance of the coils *L* (Fig. 10.6).

The spark discharge is phased to occur at the beginning of each half-cycle

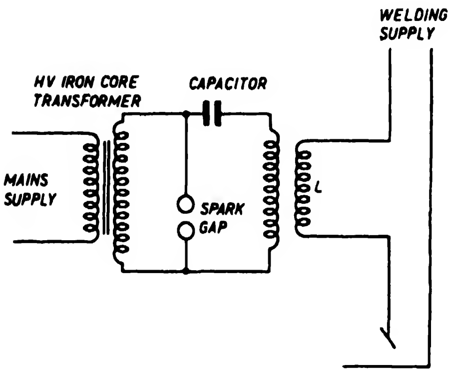
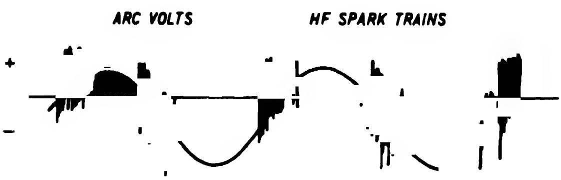


Fig. 10.5. (*left*) High-frequency spark oscillator.

Fig. 10.6. (*below*) Arc voltage with superimposed HF spark main for re-ignition and stabilization; the HF is injected on both +ve and −ve half-cycles, but is only required at the beginning of the former.



* This equipment produces radio-frequency interference (RFI). EEC regulations will, in future, prohibit the manufacture and use of this sort of equipment for starting and maintaining the TIG arc because of interference with computers, electronic systems, etc. Consequently, non-HF starting and stabilization of the TIG arc, such as lift arc (LIFTIG), pp.495–6, is necessary. Square wave a.c. does not allow the arc to be extinguished at each cycle changeover and should be used for welding aluminium where necessary with a.c. (p.502). **Use of the inverter (Chapter 5) gives a high frequency a.c.** with smooth, stable arc and no additional HF stablization.

(although for re-ignition purposes it is required only for the positive half-cycle) and is of about 5 milliseconds or less duration compared with the half-cycle duration of 10 milliseconds (Fig. 10.7). To initiate the arc, the electrode is brought to about 6 mm from the work with the HF unit and welding current switched on. Groups of sparks pass across the gap, ionizing it, and the welding current flows in the form of an arc without contamination of the electrode by touching down. The HF unit can give rise to considerable radio and TV interference and adequate suppression and screening must be provided to eliminate this as far as possible. The use of HF stabilization with the a.c. arc enables this method to be used for aluminium welding, although inherent rectification is still present, but partial rectification can be reduced to a minimum by correct phasing of the spark train.

Scratch start. Some units do not employ an HF unit for starting the arc without touch down. The tungsten is scratched momentarily onto the work and the arc is ionized. Naturally there will be some very small tungsten contamination but this will not greatly interfere with the mechanical properties of the joint in non-critical conditions.

Lift start. In this method no HF unit is used, the tungsten electrode is placed down upon the work where the welding is to begin. The operator presses a switch which connects it to the electronic control but, as yet, no current flows.

The torch is then lifted a little from the work (or tilted on the gas nozzle), the arc is struck as the electrode makes a gap from the work and it then slopes up to the values set for the work in hand. Upon releasing the switch the current slopes down to zero and thus prevents the formation of a finishing crater. With this method there is no HF interference with any other HF apparatus.

Surge injection unit. This device supplies a single pulse surge of about 300 V phased to occur at the point when the negative half-cycle changes to the

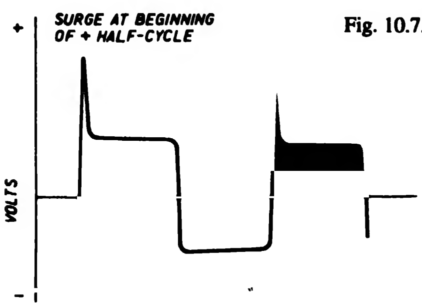


Fig. 10.7. Surge voltage superimposed on arc voltage.

positive half-cycle (Fig. 10.7), so that the pulse occurs at 20 millisecond intervals and lasts for only a few microseconds. This unit enables transformers of 80 V open-circuit voltage to be used and it does not produce the high frequency radiation of the spark oscillator and thus does not interfere to any extent with radio and TV apparatus.

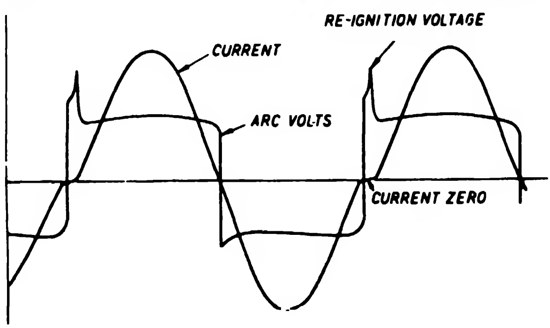
The unit consists of a rectifier which supplies d.c. to a circuit containing resistance and capacitance, a surge valve which supplies the short pulses and a trigger valve which releases the pulses into the welding circuit. The trigger valve, which is sensitive to change in arc voltage, releases the pulse at the end of the negative half-cycle, just when the positive half-cycle is beginning. As the pulse is usually unable to initiate the arc from cold, a spark oscillator is also included in the unit and is cut out of circuit automatically when the arc is established so that the surge injection unit is an alternative method to the HF oscillator for re-igniting the arc on the positive half-cycle (Fig. 10.8).

Suppression of the d.c. component in the a.c. arc

In spite of the use of the HF unit, the imbalance between the positive and negative half-cycles remains and there is a d.c. component flowing. This direct current flows through the transformer winding and saturates the iron core magnetically, giving rise to high primary currents with such heating effect that the rating of the transformer is lowered, that is, it cannot supply its rated output without overheating. The insertion of banks of electrolytic capacitors in series with the welding circuit has two effects:

(1) They offer low impedence to the a.c. which flows practically uninterrupted, but they offer very high impedance to the d.c. which is therefore suppressed or blocked.
(2) During the negative half-cycle the capacitors receive a greater charge (because of the imbalance) and during the following

Fig. 10.8. Current and arc voltage wave-forms showing re-ignition.



positive half-cycle this excess adds to the positive half-cycle voltage so that it is increased, and if the open-circuit voltage is greater than about 100 V the arc is re-ignited on each half-cycle without the aid of high-frequency currents, which can then be used for starting only. The effect of this increase in voltage on the positive half-cycle is to improve the balance of the wave (Fig. 10.8), so that the heating effect between electrode and plate is more equal and disposal of the oxide film is increased.

The value of the capacitor must be chosen so that there is no danger of electrical resonance in the circuit which contains resistance, inductance and capacitance, which would result in dangerous excessive currents and voltages irrespective of the transformer output (Fig. 10.9*a*). If external capacitors are used they may affect the current output of the transformer by altering the power factor, and this must be taken into account since the current calibrations on the set will be increased.

The cost of large banks of capacitors however is considerable and is accompanied by a high voltage across them, so that this method has been largely superseded in the units which use solid state technology and thyristor control (see later).

Power sources a.c. and d.c.

Equipment can be chosen to give a.c. or d.c. or both a.c. and d.c. from one unit and may even be designed for specific industries: (1) d.c. output for the fabrication of a variety of steels and special steels such as stainless, heat resistant and 9% Ni, etc., (2) a.c. output for fabrication aluminium and its alloys, (3) a.c. and d.c., which includes the fabrication of both the above ferrous and non-ferrous metals and it is this type that covers most types of fabrication.

Power unit a.c. For the light alloys of aluminium and magnesium a transformer similar to that used for MMA welding can be used. Cooling can be by forced draught or oil, usually the former, and primary tappings are provided on the input side for single- or three-phase 50 Hz supply, with an output voltage of about 80 V. Current control can be by tapped choke or saturable reactor and auxiliary units such as HF oscillator, d.c. component suppressor, and surge injector can be built in or fitted externally. Scratch start obviates the use of the HF oscillator but has certain disadvantages.

Power unit d.c. These units consist of a step-down transformer with input from single- or three-phase 50 Hz mains which feeds into a thyristor or silicon controlled rectifier (SCR) which gives a stepless control of current and obviates the use of other methods of current control. On larger units

there may be a two position switch for high or low current ranges, and these are usually constant voltage units.

Power units, d.c. and a.c. These units, which supply either a.c. or d.c., are connected to single- or three-phase 50 Hz mains, fed into a step-down transformer and then into a thyristor which may also act as a contactor so that there are no mechanical parts to open and close when welding is begun and ended.

The thyristors, which can be switched under load, are fitted to a heat sink and the whole is forced draught cooled. Current can be supplied for MMA and TIG and output can be for electrode +ve or −ve or a.c. by means of the controlling printed circuit.

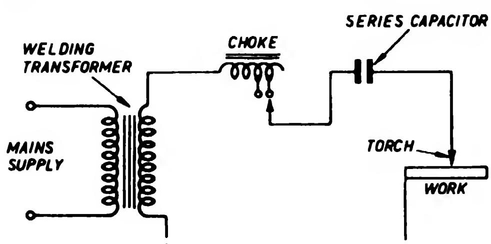
The auxiliary supply is at a lower voltage of about 110 V and there is automatic regulation for variation of the mains voltage. In addition there can be burn back control, soft start, pulse and spot welding facilities and the units are suitable for using hard or soft solid core wires and flux cored wire using either short circuit or spray transfer.*

Duty cycle

Over a period of 10 minutes, a 60% duty cycle means that the unit can be used at that particular current (about 275 A in Fig. 10.9*b*) for 6 minutes and then given 4 minutes to cool down. Increasing the welding current above that recommended for the particular duty cycle increases the quantity of heat evolved and the excessive temperature rise can lead to failure. Decreasing the welding current increases the period within the 10 minutes for which the unit can be operated. Thermal cut-outs may be fitted which trip and prevent serious damage while thyristors are bolted to a heat sink and the whole unit force draught cooled.

Exceeding the duty cycle value of current can cause overheating and may damage the unit.

Fig., 10.9. (*a*) Series capacitor used to block d.c. component



* A typical formula for obtaining the voltage drop V, across the arc when a current A is flowing is $V = 10 + (0.04A)$. Thus a current of 70 A gives a drop of ~12.8 V

Slope-in (slope-up) and soft start. The use of normal welding current at the beginning of the weld often causes burn-through and increases the risk of tungsten contamination. To prevent this a slope-in control is provided which gives a controlled rise of the current to its normal value over a preselected period of time, which can be from 0 to 10 seconds. The soft start control is available on some equipment and performs the same function but it has a fixed time of operation and can be switched in or out as required.

Slope-out (slope-down) (crater fill). The crater which would normally form at a weld termination can be filled to the correct amount with the use of this control. The crater-filling device reduces the current from that used for the welding operation to the minimum that the equipment can supply in a series of steps. The slope-out control performs the same function, but the current is reduced over a period of about 20 seconds depending upon the setting of the control (not steps). The tendency to cracking is reduced by the use of this control (Fig. 10.10).

Fig. 10.9. (*b*) Illustrating how the welding current decreases as the % duty cycle of a power unit increases.

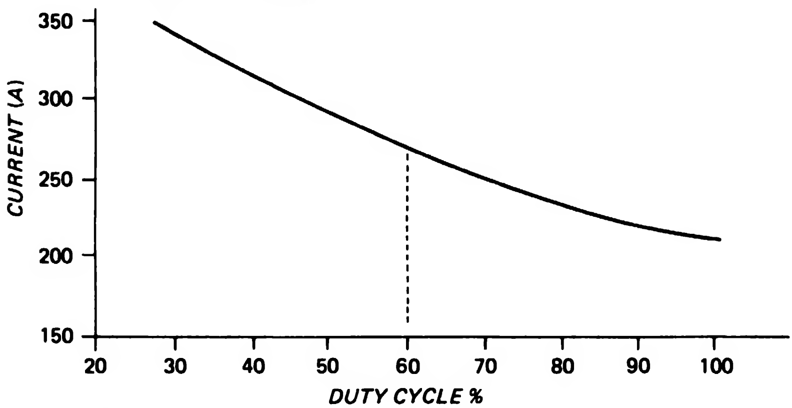
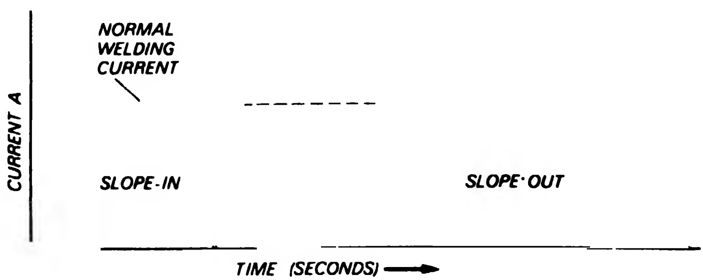


Fig. 10.10.

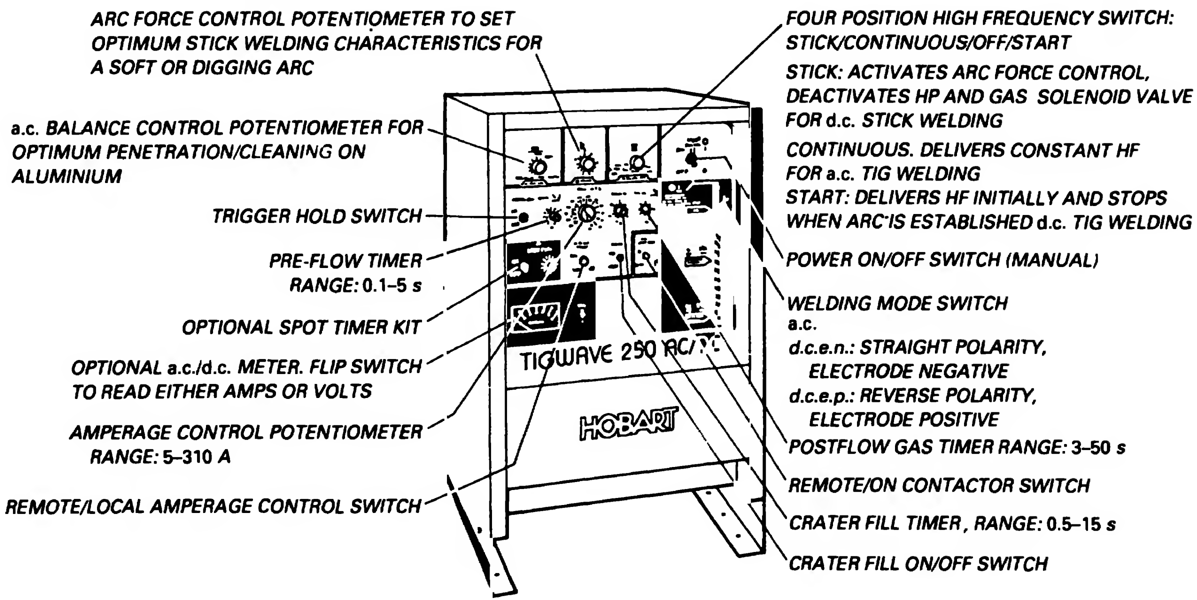


Thyristor or silicon controlled rectifier (SCR) control of welding current

The value of welding current required is set by the single dial or knob current control on the front panel of the unit. This value is compared by the control circuit (p.c.b.) with the value of output current received from the sensor in the outgoing welding line and the firing angle of the SCR's is altered to bring the output current to the value set by the operator on the control dial. Hence stepless control is achieved (Fig. 10.11*a*, *b*). A simple

Fig. 10.11. (*a*) For a.c. or d.c. TIG, a.c./d.c. low frequency pulsed TIG, a.c. or d.c. middle frequency pulsed d.c. TIG spot welding and d.c. MMA. 380–415 V 3-phase 50–60 Hz. Duty cycle 40% (10 min). Currents: d.c. TIG 5–300 A, a.c. TIG 10–300 A, d.c. MMA 10–250 A. Crater filling. Up and down slope 0–1.5 A. Pre and after flow gas. Cleaning effect control adjustment ratio 10–50%. Remote control. Weight 40 kg. HF or lift start.

Fig. 10.11. (*b*) 250 a.c./d.c. TIG MMA square wave with OC/CV feeder. Available voltages 230/380/415/500 a.c. 50 Hz OCV 80. Welding mode switch 5–310 A, a.c. or d.c.e.n., d.c.e.p. Pre and post flow gas 250 A at 40% duty cycle. Balance control penetration/cleaning. Arc force control (soft or digging arc). **(See Appendix 13, p. 778, for photograph of unit.)**



explanation of the operation of an SCR, with diagrams, is given in Appendix 5.

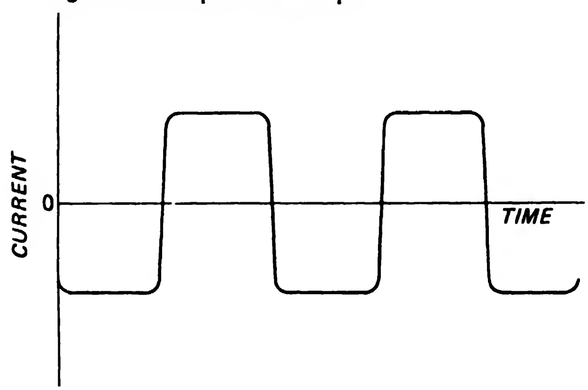
Square wave output units (a.c./d.c.)

Power units are now available in which the voltage and current waves are not sinusoidal, but have been modified by solid state technology and using printed circuit boards (p.c.b.'s) to give a very rapid rise of the a.c. wave from zero value to maximum value to give a 'square wave' output (Fig. 10.12).

When TIG welding aluminium using a sinusoidal wave form current the arc tends to become unstable and the electrode is easily overloaded. This gives tungsten inclusions in the weld (spitting) and leads to faults in the weld bead and more rapid consumption of the tungsten electrode. Square wave current overcomes these drawbacks and the arc is greatly stabilised and risk of inclusions greatly reduced. In addition MMA welding characteristics are greatly improved and the arc is smooth with reduced spatter.

The units are designed for precision a.c. TIG welding of aluminium, etc., and for d.c. TIG and manual metal arc welding. They have a transformer and a silicon bridge rectifier, SCR or thyristor with a square wave output. A memory core stores energy proportional to the previous half-cycle and then injects it into the circuit just as the wave passes through zero at the beginning of the next half-cycle. The rapid rise of the wave from zero to maximum, of about 80 microseconds from peak to peak (Figs. 10.13 and 14) means that the high frequency and high voltage at the beginning of the cycle needed to initiate the arc and often to keep it ionized without touchdown, need only be applied when the arc is first initiated. After this first initiation the HF is switched off automatically and the rapid rise of voltage from peak

Fig. 10.12. a.c. square wave output.

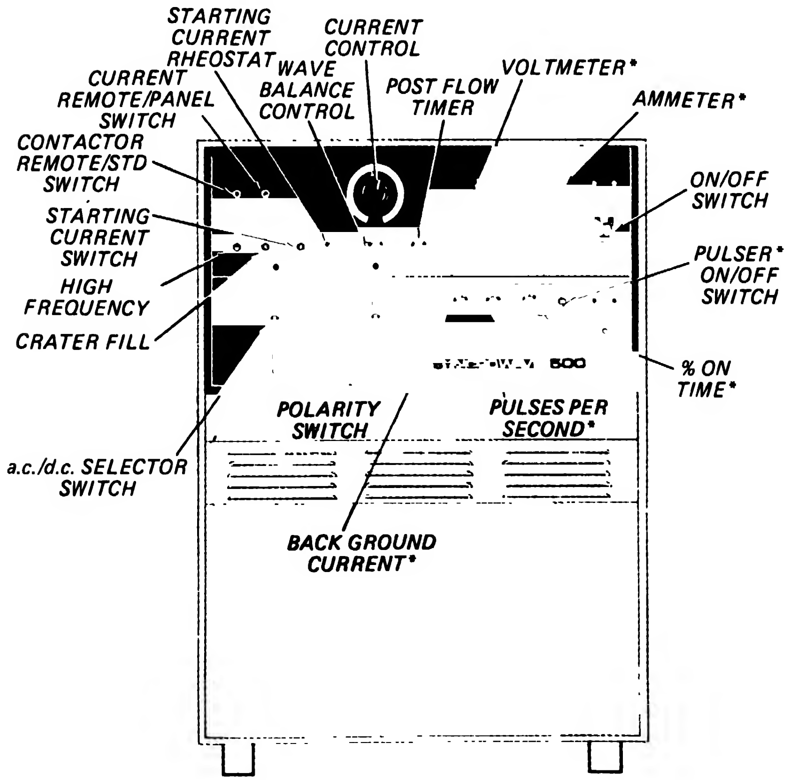


to peak keeps the arc ionized without application of the HF. A switch enables this HF to be used continuously if required although its continuous use may interfere with radio frequency apparatus in the vicinity.

Variation in mains voltage is compensated automatically, there is provision for MMA, pulse and spot welding and often there may be two ranges of current, either of which can be controlled by the one knob control (Fig. 10.13).

Soft start (slope-up) and crater fill (slope-down) are provided with pre- and post-gas and water supply controls. Pulse duration, height and background and wave balance controls are also fitted.

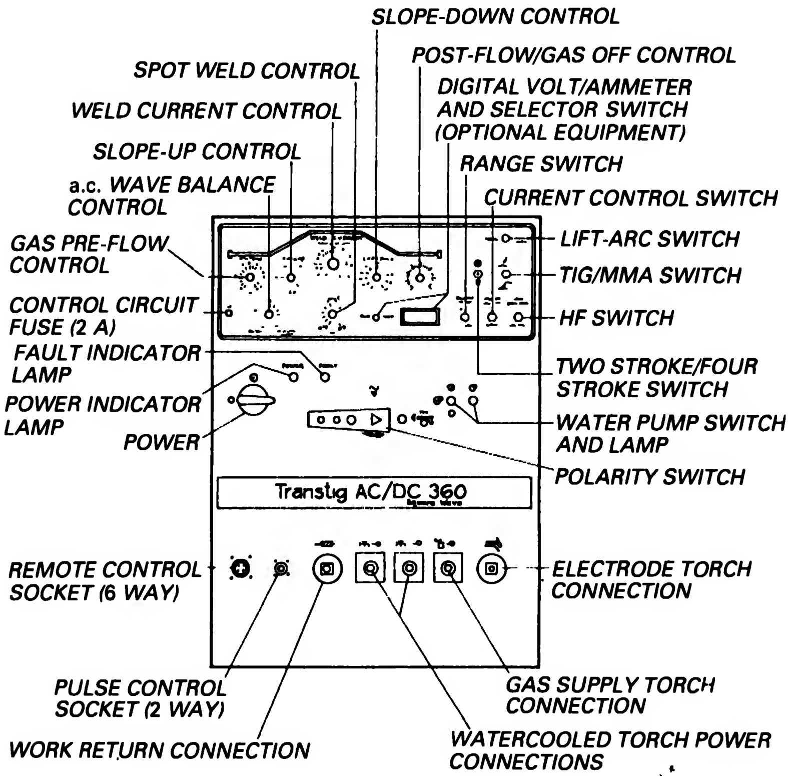
Fig. 10.13. Syncrowave 300 and 500 A square wave a.c., d.c., power unit for TIG and MMA welding Input 220–576 V as required, mains voltage compensated. 500 A model gives 500 A at 100% duty cycle. Solid state contactors, slope-in and slope-out Pulsed mode for improved penetration and control of weld pool. Rectification by SCR's with one knob control of welding current 300 A model has dual current range, 5-75 A and 15–375 A, 500 A model has single range 25-625 A Square wave output has wave balance control Post timer for gas and water. Slope-up and slope-down (crater fill).



Wave balance control a.c.

On square wave equipment the wave balance control enables either tungsten electrode or work to be biased as required. **Fig. 10.15** indicates how this is used for controlling penetration and cleaning action. (1) is a balanced wave. Moving the control to one side gives a wave balance (2) in which the tungsten electrode is positive polarity for a larger period,

Fig. 10.14. Square wave a.c. and d.c. 260 A (also a 360 A model) for a.c. and d.c. TIG and MMA, 50 Hz. Input 3-phase 380–415 V (or single phase 220 V, 200 A model). Output 10–375 A, 30% duty cycle, 375 A, 35 V; 60% cycle, 300 A, 32 V 100%; cycle 235 A, 29 V. Two current ranges, minimum current 10 A. Pre and post flow gas, slope up and slope down, spot timer. 80 OCV. Start lift arc and HF. TIG switch latching torch. Remote and pulse control optional extras. **(See Appendix 13, p.779, for photograph of unit.)**



giving maximum cleaning but with minimum penetration. With the control in the other direction the greatest heat is in the work so that we have maximum penetration but with minimum cleaning (3). With d.c. TIG welding as with MMA the control is set for a balanced wave.

Electrical contactors

The contactors control the various circuits for welding, inert gas, water flow and ancillary equipment. The contactor control voltage is of the order of 25-45 V and if the TIG head is machine mounted, a 110 V supply for the wire feed and tractor is provided. The post-weld argon flow contactor allows the arc to be extinguished without removing the torch with its argon shield from the hot weld area, thus safeguarding the hot electrode end and weld area from contamination whilst cooling. An argon water purge is also provided and contactors may be foot-switch operated for convenience. Where the ancillary equipment is built into one unit an off-manual metal arc TIG switch enables the unit to be used for either process.

With the advanced SCR method of control the SCR's act as a contactor so that there are no mechanical contactors in the welding current circuit. Cooling is by heat sink and forced draught and this method is very reliable since there are no moving parts

Gas regulator, flowmeter and economizer

The gas regulator reduces the pressure in the argon cylinder from 175 or 200 bar down to 0 3.5 bar for supply to the torch **(Fig. 10.16*a*** and *b*). The flowmeter, which has a manually operated needle valve, controls the argon flow from 0–600 litres/hour to 0–2100 litres/hour according to type **(Fig. 10.16*c*).**

The economizer may be fitted in a convenient position near the welder and when the torch is hung from the projecting lever on the unit, argon gas and (if fitted) water supplies are cut off. A micro-switch operated by the lever can also be used to control the HF unit.

Fig. 10.15. Wave balance control

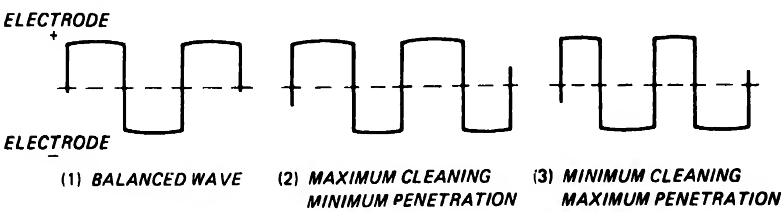


Fig. 10.16. (*a*) Single-stage preset argon regulator and flowmeter.

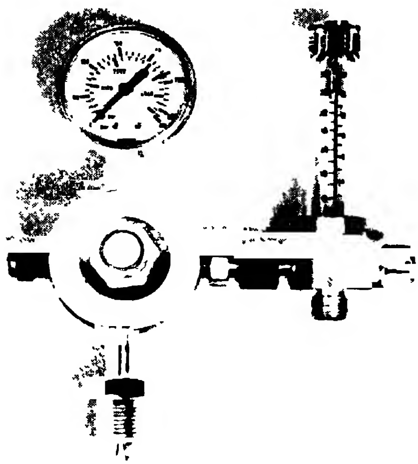
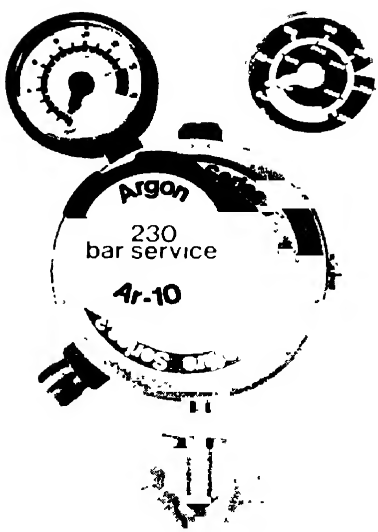


Fig. 10.16. (*b*) Two-stage argon regulator



Additional equipment

Add-on equipment can be used with existing transformers and rectifiers. The equipment shown in Fig. 10.17 is fitted with a pulse generator and can be connected to a thyristor controlled rectifier power unit or to a.c. or d.c. arc welding sources. When connected to a d.c. source the pulse generator is used for arc ignition only, being automatically cut off after ignition, but it cuts in again if required to establish the arc. When used with an a.c. source the pulse generator ensures arc ignition without touchdown and ensures the re-ignition of the arc when welding. Soft start, crater fill, current control with one knob and remote control facilities are also fitted.

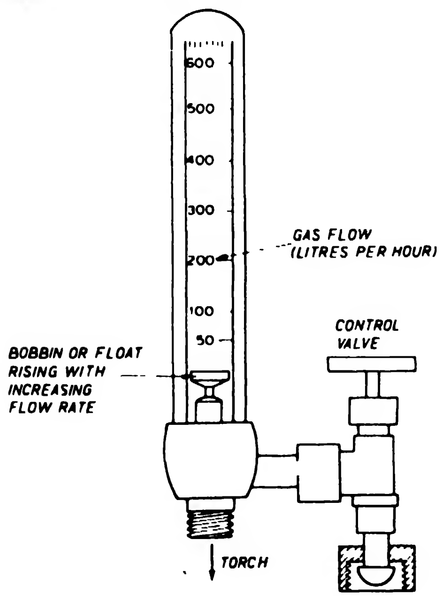
Torch

There is a variety of torches available varying from lightweight air cooled to heavy duty water cooled types (Fig. 10.18*a* and *b*). The main factors to be considered in choosing a torch are:

(1) Current-carrying capacity for the work in hand.
(2) Weight, balance and accessibility of the torch head to the work in hand.

The torch body holds a top-loading compression-type collet assembly which accommodates electrodes of various diameters. They are securely gripped yet the collet is easily slackened for removal or reposition of the electrode. As the thickness of plate to be welded increases, size of torch and

Fig. 10.16. (*c*) Argon flowmeter.



electrode diameter must increase to deal with the larger welding currents required.

Small lightweight air cooled torches rated at 75 A d.c. and 55 A a.c. are ideal for small fittings and welds in awkward places and may be of pencil or swivel head type. Collet sizes on these are generally 0.8 mm, 1.2 mm and 1.6 mm diameter. Larger air cooled torches of 75 A d.c. or a.c. continuous rating or 100 A intermittent usually have a collet of 1.6 mm diameter. Air or water cooled torches rated at 300 A intermittent may be used with electrodes from 1.6 to 6.35 mm diameter and can be fitted with water cooled shields while heavy duty water cooled torches with a water cooled nozzle of 500 A a.c. or d.c. continuous rating and 600 A intermittent employ larger electrodes. A gas lens can be fitted to the torch to give better gas coverage and to obtain greater accessibility or visibility.

Normally, because of turbulence in the flow of gas from the nozzle, the electrode is adjusted to project up to a maximum of 4–9 mm beyond the nozzle (Fig. 10.20). By the use of a lens which contains wire gauzes of coarse and fine mesh, turbulence is prevented and a smooth even gas stream is obtained, enveloping the electrode which, if the gas flow is suitably increased, can be used on a flat surface projecting up to 19 mm from the nozzle orifice, greatly improving accessibility. The lens is screwed on to the torch body in place of the standard nozzle and as the projection of electrode from nozzle is increased the torch must be held more vertically to the work to obtain good gas coverage.

The ceramic nozzles (of alumina, silicon carbide or silicon nitride),

Fig. 10.17. Add-on unit for TIG welding.

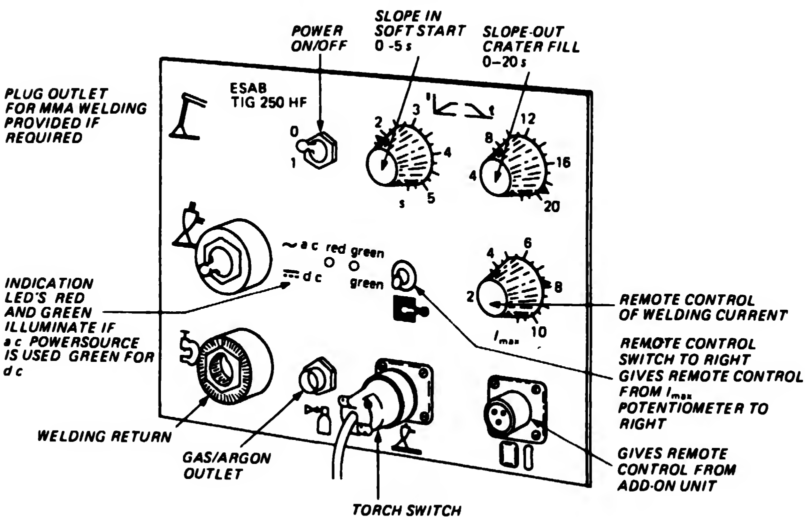


Fig. 10.18. (*a*) 160 A air-cooled torch (manual). Torches are air cooled for lower currents and water cooled for higher currents.

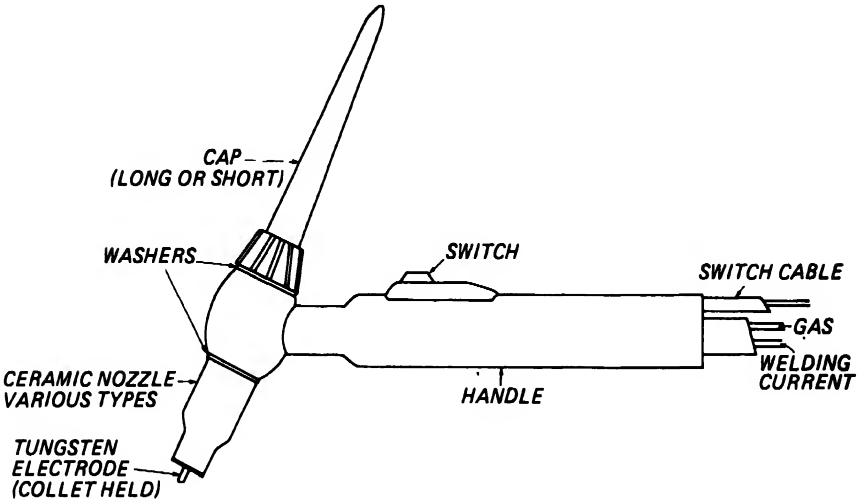
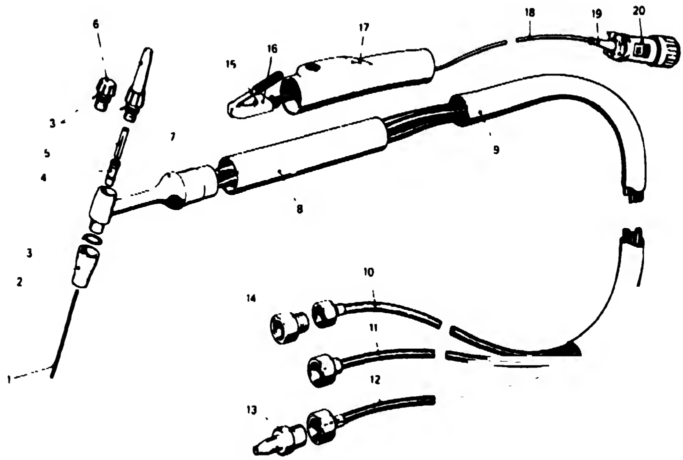


Fig. 10.18. (*b*) A water-cooled torch.



Key:

1 Thoriated or zirconiated tungsten electrode (0.8, 1 2, 1 6, 2 4, 3.2 mm diameter)
2 Ceramic nozzle
3 O ring
4 Collet holder.
5 Collet (sizes as above to take various diameters of electrodes)
6 Electrode cap (long and short)
7 Body assembly
8 Sheath.
10 Argon hose assembly
11 Water hose assembly
12. Power cable assembly
13 Adapter power/water; required only in certain cases
14 Adapter argon; required only in certain cases
15 Switch actuator
16 Switch
17 Switch-retaining sheath
18 Cable, 2 core
19 Insulating sleeve
20 Plug.

which direct the flow of gas, screw on to the torch head and are easily removable for cleaning and replacement. Nozzle orifices range from 9.5 to 15.9 mm in diameter and they are available in a variety of patterns for various applications. Ceramic nozzles are generally used up to 200 A a.c. or d.c. but above this water cooled nozzles or shields are recommended because they avoid constant replacement.

Electrodes (see also BS 3019, Pts 1 and 2)

The electrode may be of pure tungsten but is more generally of tungsten alloyed with thorium oxide (thoria ThO_2) or zirconium oxide (zirconia ZrO_2).

The thoriated electrode is generally used with d.c.; 1% thoriated is often used but 2% thoriated gives good arc striking characteristics at low d.c. values. Although thoriated electrodes may be used for a.c. welding, it is generally better to use zirconiated.

Tungsten has a melting point of 3380 °C and a boiling point of 5950 °C so that there is only little vaporization in the arc and it retains its hardness when red hot. Though the electrodes are costly they are classed as virtually 'non-consumable'. They are supplied with a ground grey finish to ensure good collet contact, electrode diameters being 0.5, 1.2, 2.4, 3.2, 4.0, 4.8, 5.6 and 6.4 mm for zirconiated electrodes with additional sizes for 1% thoriated electrodes (e.g. 0.8, 8.0, 9.5 mm).

Though pure tungsten electrodes may be used, thoriated tungsten electrodes give easier starting on d.c. with a more stable arc and little possibility of tungsten contamination in the weld and they have a greater current carrying capacity for a given diameter than pure tungsten. However, when they are used on a.c. difficulty is encountered in maintaining a hemispherical end on the electrode. Thus zirconiated electrodes are preferred for a.c. welding because of good arc starting characteristics and the reduced risk of tungsten contamination. Zirconiated tungsten electrodes are used for high quality welds in aluminium and magnesium.

Selection of electrode size is usually made by choosing one near the maximum range for electrode and work. Too small an electrode will result in overheating and thus contamination of the work with tungsten, while too large an electrode results in arc control difficulty. Aim for a shining hemispherical end on the electrode, the lengths being usually 75 or 150 mm.

In the table of electrode current ratings it should be noted that the figures given are for class 1 welding using balanced a.c. waveform. Higher currents than these may be used by experienced welders.

Electrode grinding

Usually electrodes need grinding to a point only when thin materials are to be welded. They should be ground on a fine grit, hard abrasive wheel used only for this purpose to avoid contamination, ground with the electrode in the plane of the wheel and rotated while grinding (Fig. 10.19).

Electrode current ratings (BS 3019, Pts 2 and 3)

d.c.; thoriated electrodes								
Electrode diameter (mm)	0.5	1.2	1.6	2.4	3.2	4.0	4.8	
Max current (A)	20	60	70	120	200	300	370	
Balanced wave a.c.[a]								
Electrode diameter (mm)	0.5	1.2	1.6	2.4	3.2	4.0	4.8	6.4
Maximum current (A)	15	50	60	80	120	160	250	320

[a] Square wave has slightly higher values. Thoriated may be used but zirconiated is preferable.

Note. These are BS values. Experienced welders may use higher currents. Ratings on a.c. are roughly 40% lower than using d.c. electrode −ve (DCSP) and 60% duty cycle.

Pulsed current TIG welding (see also Chapter 9, pulsed MIG welding)

In MMA welding the operator chooses the current for a given joint and then, when making the weld, uses his skill to balance the heat input by the arc with the heat output due to the melting of the metal and conduction, convection and radiation by the work. He keeps this balance by electrode angle, amount of weave and rate of travel and achieves correct penetration.

In manual TIG welding this balance is achieved by weaving and the addition of filler metal. With pulsed current TIG welding the melting of the metal is controlled by pulsing the current at a higher value and at regular intervals.

There are two current values, the background current which is steady throughout and the pulsed current which is intermittent but at regular intervals. This pulse increases the energy in the arc and melts off an amount of filler rod to allow correct penetration, and then when the pulse ceases there is left only the background current to keep the arc ionized and the weld metal freezes.

The weld thus progresses as a series of overlapping spot welds and by judicious selection of background current and pulse height (amount of

current) and duration the operator has complete control of welding parameters. It can be seen that this method is very advantageous for thin and medium sections, positional welding and in mechanized TIG welding. Pulse facilities are now incorporated on most power units.

Firstly the background current is set at about 5 - 12 A, then the pulse is set

Fig. 10.19. Tungsten electrode preparation

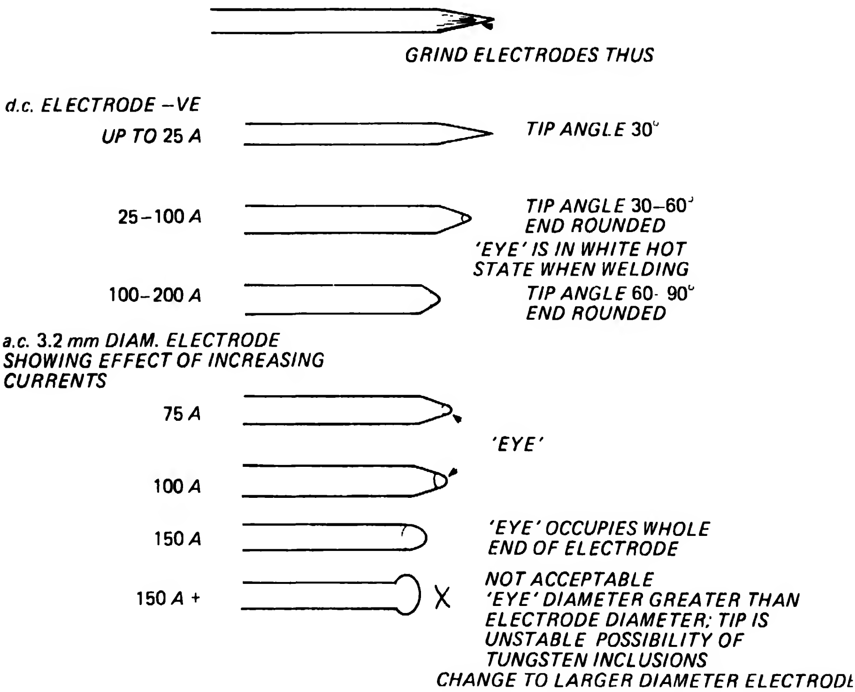
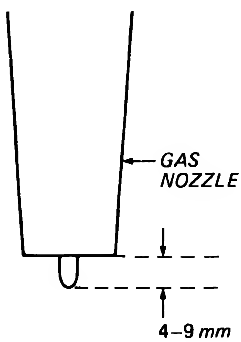


Fig. 10.20. Electrode protrusion. No gas lens. In awkward places protrusion can be increased. Gas shield *must* cover area being welded

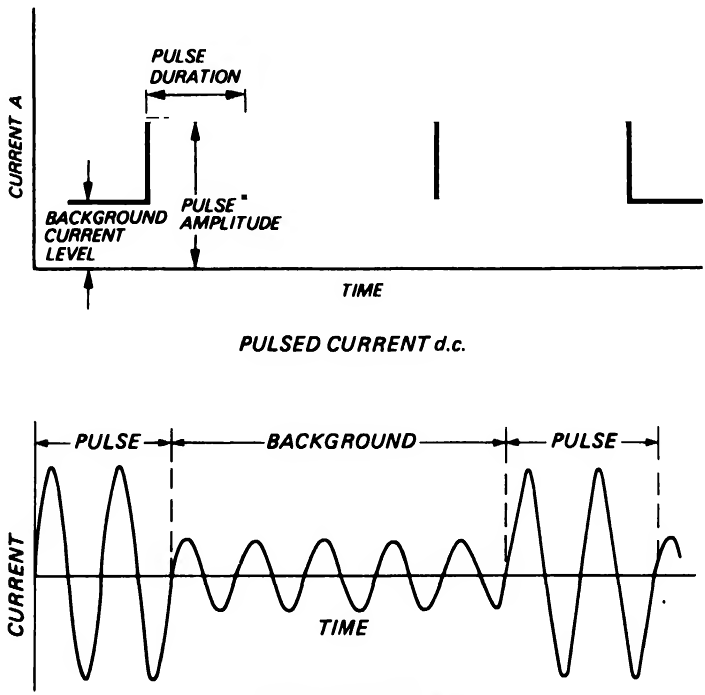


at a value which depends upon the metal to be welded, say 140 A, and the duration is varied until the correct amount of penetration is achieved (remember that the heat input depends upon (pulse current × duration). The pulse heats up the molten pool, more filler wire is melted off, penetration is achieved and the pulse ceases; the metal then solidifies, cooling slightly ready for the next pulse.

Fig. 10.21 shows a basic pulse for d.c. and a.c. and since there is such control over the molten pool, fit-up tolerances are not so severe as in welding with non-pulsing current. Pulsed TIG is used on mild and low-alloy steels, stainless steels, heat-resistant steels, titanium, inconel, monel, nickel and aluminium and its alloys and for the orbital welding of thin pipes.

The pulse frequency can be increased from about 1 to 10 pulses per second by the use of the pulse control, while the width control varies pulse width and the background current control varies this as a constant percentage of the weld current as shown in Fig. 10.22. Using these controls

Fig. 10.21. Pulsed current. Pulses are variable in frequency (pulses per second) and width (peak current).



PULSED CURRENT d.c.

PULSED CURRENT a.c.

enables the operator to control the heat input into the weld and thus the root penetration.

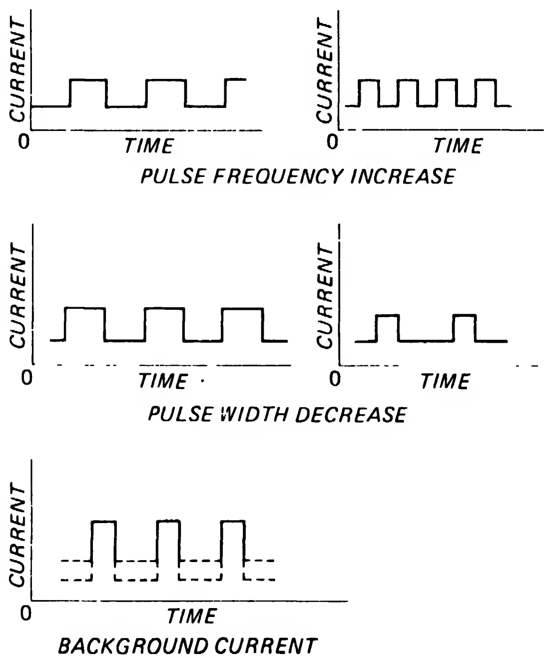
Safety precautions

The precautions to be taken are similar to those when manual metal arc welding. In addition however there is the high voltage unit used for arc initiation without touchdown. This unit is similar in output to that of the car ignition coil and care should be taken when it is switched on. Do not let the electrode touch the body when switched on or a severe shock will be felt. BS 639 recommended EW filters are graded according to welding current thus: up to 50 A, no. 8; 15–75 A, no. 9; 75–100 A, no. 10; 100–200 A, no 11; 200–250 A, no, 12; 250 300 A, no. 13 or 14.

It will be noted that these filters are darker than those used for similar current ranges in MMA welding. The TIG (and MIG) arcs are richer in infra-red and ultra-violet radiation, the former requiring some provision for absorbing the extra associated heat, and the latter requiring the use of darker lenses.

It is recommended that the student reads the booklet *Electric arc welding, safety, health and welfare*, new series no. 38; published for the Department

Fig. 10.22



of Employment by HMSO; and also BS 679, *Filters for use during welding*; British Standards Institution.

Welding techniques

Carbon steel

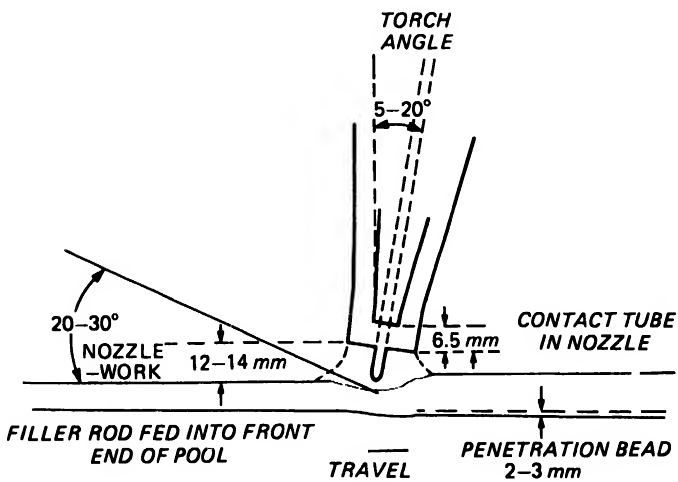
TIG welding can be used with excellent results on carbon steel sheet and pipework, and for this and other steel welds the angle of torch and rod are similar to that for aluminium, namely torch 80–90° to line of travel and filler wire at 20–30° to the plate (Fig. 10.23). The filler wire is chosen to match the analysis of the plate or pipe.

The welding of aluminium and its alloys

The table (p. 517) gives details of the filler wire types for welding the various alloys. Angles of torch and filler wire are shown in Fig.10.23.

Casting alloys. Those with high silicon content, LM2, LM6, LM8 and LM9, can be welded to the Al–Mg–Si alloys with Al–Si 4043 wire. Similarly the Al–Mg casting alloys LM5 and LM10 can be welded to the wrought alloys using 5356 wire. Serious instability of LM10 may occur due to local heating and the alloy must be solution treated after welding.

Fig. 10.23. Angles of torch and rod showing typical weld: aluminium alloy plate 11 mm thick 70–80° prep., 1.5 mm root face, no gap, a.c. volts 102, arc volts drop, 17–18 volts: electrode 4.8 mm diameter, current 255 A, arc length approx. 4 mm.



Technique. The supply is a.c. and the shielding gas pure argon. Remember that, with TIG and MIG processes using shielding gases, the welding position must be protected from stray draughts and winds which will destroy the argon shield. This is particularly important when site welding and (waterproof) covers or a tent to protect welder and gas shields from wind and rain must be erected if they are to be fully protected. Pre-heating is required for drying only to produce welds of the highest quality. All surfaces and welding wire should be degreased and the area near the joint and the welding wire should be stainless steel wire brushed or scraped to remove oxide and each run brushed before the next is laid. After switching on the gas, water, welding current and HF unit, the arc is struck by bringing the tungsten electrode near the work (without touching down). The HF sparks jump the gap and the welding current flows.

Arc length should be about 3 mm. Practise starting by laying the holder on its side and bringing it to the vertical position using the gas nozzle as a fulcrum, or use a striking plate and get the tungsten hot before starting the weld. (This does not apply to scratch start.) The arc is held in one position on the plate until a molten pool is obtained and welding is commenced, proceeding from right to left, the rod being fed into the forward edge of the molten pool and always kept within the gas shield. It must not be allowed to touch the electrode or contamination occurs. A black appearance on the weld metal indicates insufficient argon supply. The flow rate should be checked and the line inspected for leaks. A brown film on the weld metal indicates presence of oxygen in the argon while a chalky white appearance of the weld metal accompanied by difficulty in controlling the weld indicates excessive current and overheating. The weld continues with the edge of the portion sinking through, clearly visible, and the amount of sinking, which determines the size of the penetration bead, is controlled by the welding rate.

Run-on and run-off plates are often used to prevent cold starts and craters at the end of a run, which may lead to cracking. Modern sets have slope-up and slope-down controls which greatly assist the welding operation but it is as well to practise using these plates.

Preparations for single V butt joints are shown in Fig. 10.24*a* while 10.24*b* shows a backing strip in position.

Tack welding and the use of jigs for line-up is similar to that used for steel. The tacks should be reduced in size by chiseling or grinding before welding the seam and care should be taken, when breaking any jigs away that were temporarily welded in, that damage does not occur to the structure or casting.

Aluminium and its alloys. Filler rod guide – TIG and MIG

Parent metal	6061 6063 6082	5083	5454	5154A 5251	3103	1050A
1050A	4043 5356(3)	5356 4043	4043 5183 5356	4043 5183 5356	4043 5356 1050A(1)	4043 1050A(1) (2)
3103	4043 5356(3)	5356 5183	5154A 5183 5356	5154A 5183 5356	4043 1050A 5356	
5154A 5251	5356 5183 4043	5356 5183 5556A	5356 5183 5154A	5356 5183		
5454	5356 5183 4043	5356 5183 5556A	5154A 5554(2) 5356			
5083	5356 5183 5556A	5183 5356 55556A				
6061 6063 6083	4043 5356(3) 5183					

(1) corrosive conditions
(2) elevated temperatures
(3) colour matching (after anodizing)

Old designations

1050A	1B
5154A	NG5
5356	NG6
5183	NG8
4043	NG21
5554	NG 52
5556	NG 61

Examples of preparation: Flat butt joints, no backing

Plate thickness (mm)	No. of runs	Current (A)	Filler rod diam. (mm)
2.0	1	100–110	2.4
2.4	1	120	3.2
3.2	1	130–160	3.2
4.8	2	230	4.8
6.4	2	240	4.8

Plate thickness (mm)		
2	Butt no gap	
2.4	Butt 0.8 mm gap	
3.2	Butt 0.8 mm gap	

TIG tack welding is used for line-up of plate and tube before finally MIG welding the seam. Temporary backing bars are grooved to the shape of the underbead and made of mild or stainless steel. These help to form and shape the penetration bead when root runs cannot be made and control of penetration is difficult. When ungrooved bars are used they should be removed after welding, the root run back-chipped and a sealing run made. Any backing strips to be welded in place should be of aluminium alloy, tack welded in place and fused in with the root run.

The vertical double-operator method (Fig. 10.25), using filler wire on one side only, gives sound non-porous welds with accurate penetration bead controlled by one operator 'pulling through' on the reverse side. There is excellent argon shielding from both sides but the method is expensive in man-hours of work and needs more skill. It however reduces residual stresses as there is less total heat input and welding speed is increased.

Magnesium and magnesium alloys

Equipment is similar to that for the aluminium alloys and the technique similar, welding from right to left with a short arc and with the same angles of torch and filler rod, with pure argon as the shielding gas and an a.c. supply. Little movement of the filler rod is required but with material over 3 mm thick some weaving may be used. For fillet welding the torch is held so as to bisect the angle between the plates and at sufficient angle from the vertical to obtain a clear view of the molten pool, with

Fig. 10.24. (*a*) Manual TIG process: preparation of aluminium and aluminium alloy plate. Single V butt joints. Flat. Plate thickness 4.8 mm 9.5 mm, root run may be back chipped and a sealing run made, though this adds to the cost of the weld

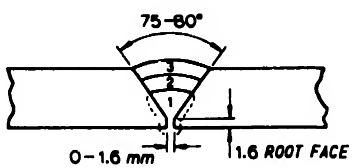
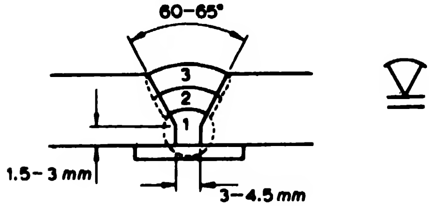


Fig. 10.24. (*b*) Use of backing strip and preparation.



enough weave to obtain equal leg fusion. Tilted fillets are used to obtain equal length.

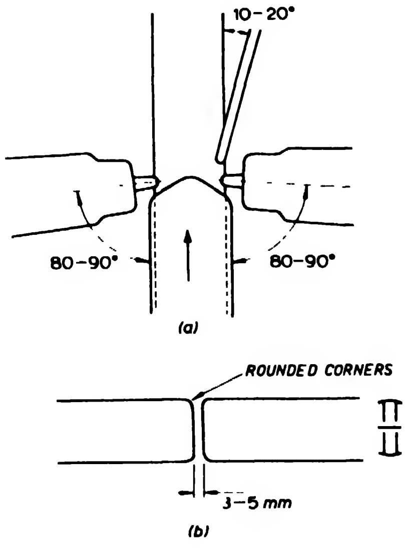
The material is supplied greased or chromated. Degreasing removes the grease and it is usual to remove the chromate by wire brushing from the side to be welded for about 12 mm on each side of the weld and to leave the chromate on the underside where it helps to support the penetration bead. No back purge of argon is required. The surface and edges should be wire brushed and the filler rod cleaned before use. Each run should be brushed before the next is laid.

Backing plates can be used to profile the underbead and can be of mild steel, or of aluminium or copper 6.4–9.5 mm wide, with grooves 1.6–3.2 mm deep for material 1.6–6.4 mm thick. (Fig. 10.26.)

Jigs, together with correct welding sequence, can be used to prevent distortion, but if it occurs the parts can be raised to stress relief temperatures of approximately 250°–300°C. Ensuring sufficient flow of argon will prevent any oxidized areas, porosity, and entrapped oxides and nitrides.

Welding rods are of similar composition to that of the plate and the table indicates the relative weldability of similar and dissimilar alloys. It is not recommended that the Mg–Zr alloys should be welded to alloys containing Al or Mn.

Fig. 10.25. (*a*) Angles of torches and filler wire (*b*) Double operator vertical welding aluminium alloys.

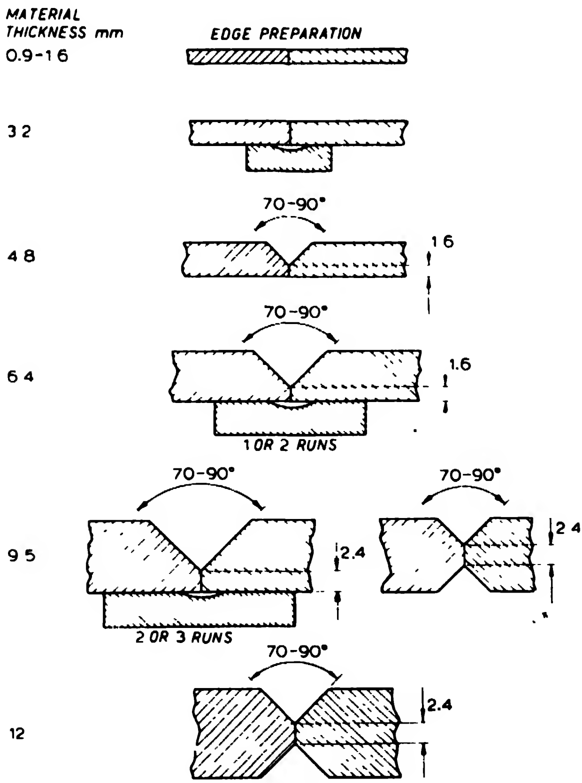


Typical magnesium alloy welding rod, composition and suitability

Elektron alloy	Zn%	Zr%	RE%	Others%	MEL welding rod type
RZE 1	2.0–3.0	0.5–1.0	2.5–4.0		W 6
RZ5	3.5–5.0	0.4 1.0	1.2–1.75		W 7
ZT1	1.7-2.5	0.5–1.0	0.1	2.5–4.0 Th	W 1
TZ6	5.2–6.0	0.5–1.0	0.2	1.5 2.2 Th	W 12
MSR B	0.2	0.4–1.0	2.2 2.7	2.0-3.0 Ag	W 13
AM503	0.03	0.01	—	1.3 1.7 Mn, 0.02 Ca	W 2
AZ31	0.7 1.3		—	2.5-3.5 Al, 0.04 Ca	W 15
A8	0.4 1.0	—		0.1 Sn, Cu, Si, Fe, Ni, to 0.4 max, 7.5-8.1 Al	W 14

Note. RE Rare earths.

Fig. 10.26. Suitable edge preparations for magnesium alloy butt welds (dimensions in mm)



For fillet welds the torch is held at about 90° to the line of travel and roughly bisecting the angle between the plates, so that the nozzle is clear of either plate, and it is often necessary to have more projection of the wire beyond the nozzle to give good visibility, but it should be kept to a minimum. Tilted fillets give a better weld profile and equal leg length. The table gives recommended filler wires for the various alloys.

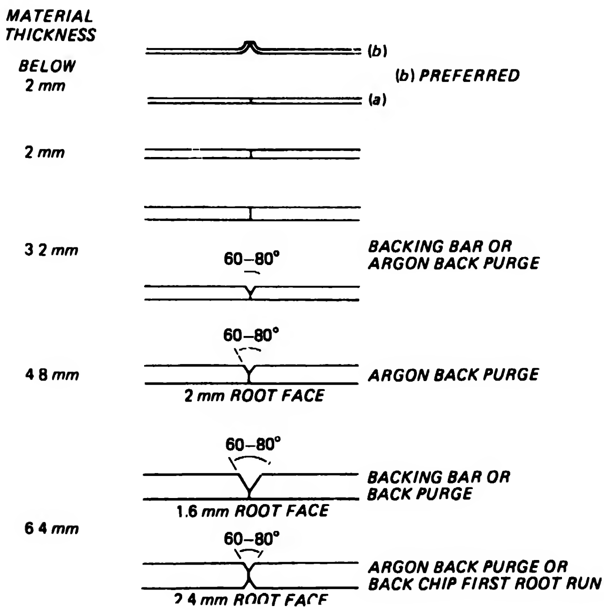
Stainless and heat-resistant steel

The production welding of stainless steel by this process is apt to be rather slow compared with MMA, MIG or pulsed arc. (See the section on the MMA welding of stainless steel.)

Areas adjacent to the weld should be thoroughly cleaned with stainless steel wire brushes and a d.c. supply with the torch negative used. The shielding gas is pure argon or argon–hydrogen mixtures (up to 5%) which give a more fluid weld pool, faster rate of deposition (due to the higher temperature of the arc), better 'wetting' and reduction of slag skin by the hydrogen.

The addition of oxygen, CO_2 or nitrogen is not recommended. Joint preparation is given in Fig. 10.27.

Fig. 10.27. Preparation of stainless steel and corrosion- and heat-resistant steels (TIG and MIG.)



Technique. The torch is held almost vertically to the line of travel and the filler rod fed into the leading edge of the molten pool, the hot end never being removed from the argon shield. Electrode extension beyond the nozzle should be as short as possible: 3.0–5.0 mm for butt and 6.0–11.0 for fillets. To prevent excessive dilution, which occurs with a wide weave, multi-run fillet welds can be made with a series of 'stringer beads'. The arc length should be about 2 mm when no filler wire is used and 3–4 mm with filler. Gas flow should be generous and a gas lens can be used to advantage to give a non-turbulent flow. Any draughts should be avoided.

Nickel alloys

Although this process is very suitable for welding nickel and its alloys it is generally considered rather slow, so that it is mostly done on thinner sections of sheet and tube.

Shielding gas should be commercially pure argon and addition of hydrogen up to 10% helps to reduce porosity and increases welding speeds especially for MONEL* alloy and Nickel alloy 200. Helium has the same advantages, greatly increasing welding speed. Great care should be taken to avoid disturbance of the protective inert gas shield by draughts, and the largest nozzle diameter possible should be used, with minimum distance between nozzle and work. The use of a gas lens increases the efficiency of the shield and gives increased gas flow without turbulence. Argon flow is of the order of 17–35 litres per hour for manual operation and higher for automatic welding. Helium flow should be about $1\frac{1}{2}$–3 times this flow rate.

The torch is held as near 90° to the work as possible – the more acute the angle the greater the danger of an aspirating effect causing contamination of the gas shield. Electrodes of pure, thoriated or zirconiated tungsten can be used, ground to a point to give good arc control and should project 3–4.5 mm beyond the nozzle for butt welds and 6–12 mm for fillets.

Stray arcing should be avoided as it contaminates the parent plate, and there should be no weaving or puddling of the pool, the hot filler rod end being kept always within the gas shield, and fed into the pool by touching it on the outer rim ahead of the weld. The arc is kept as short as possible – up to 0.5 mm maximum when no filler is used.

To avoid crater shrinkage at the end of a weld a crater-filling unit can be used or failing this, extension tabs for run-off are left on the work and removed on completion. Fig. 10.28 gives suitable joint preparations.

For vertical and overhead joints the technique is similar to that for steel, but downhand welding gives the best quality welds.

Filler wires for TIG, PLASMA and MIG dip, spray and pulsed submerged arc filler metals and fluxes

Material	Filler wire TIG/plasma MIG dip, pulsed	Filler wire MIG spray	Filler wire/flux submerged arc
Nickel alloys 200, 201	Nickel alloy 61	Nickel alloy 61	Nickel alloy 61, INCOFLUX* 6
MONEL* alloy 400	MONEL* alloy 60	MONEL* alloy 60	MONEL* alloy 60, INCOFLUX* 5
MONEL* alloy K500	MONEL* alloy 60	Not recommended	Not recommended
Cupro–nickel alloys	MONEL* alloy 67	MONEL* alloy 67	MONEL* alloy 67, INCOFLUX* 8
INCONEL* alloy 600	INCONEL* alloy 82	INCONEL* alloy 82	INCONEL* alloy 82, INCOFLUX* 4
INCONEL* alloy 601	INCONEL* alloys 601, 82, 625	INCONEL* alloys 82, 625	INCONEL* alloys 82, 625, INCOFLUX* 4, 7
INCONEL* alloy 625	INCONEL* alloy 625	INCONEL* alloy 625	INCONEL* alloy 625, INCOFLUX* 7
INCONEL* alloy 617	INCONEL* alloy 617	INCONEL* alloy 617	Not recommended
INCONEL* alloy 690	INCONEL* alloys 82, 625	INCONEL* alloys 82, 625	Not recommended
INCONEL* alloy 718	INCONEL* alloys 625, 718	Not recommended	Not recommended
INCONEL* alloy X-750	INCONEL* alloy 718	Not recommended	Not recommended
INCO* alloy C-276	INCO* alloy C-276	INCO* alloy 276	Not recommended
INCO* alloy HX	INCO* alloy HX, INCONEL* alloy 617	INCO* alloy HX, INCONEL* alloy 617	Not recommended
INCO* alloy G-3	INCONEL* alloy 625	INCONEL* alloy 625	Not recommended
INCOLOY* alloys 800, 800H, 800HT	INCONEL* alloys 82, 625, 617	INCONEL* alloys 82, 625, 617	INCONEL* alloys 82, 625, INCOFLUX* 4, 7
INCOLOY* alloy 825	INCOLOY* alloy 65	INCOLOY* alloy 625	INCONEL* alloy 625, INCOFLUX* 7
INCOLOY* alloy DS	NC 80/20	Not recommended	Not recommended
NIMONIC* alloy 75	NC 80/20	NC 80/20	INCONEL* alloy 82, INCOFLUX* 4
BRIGHTRAY* alloy series	NC 80/20	Not recommended	Not recommended
NILO* alloy series	Nickel alloy 61, INCONEL* alloy 82	Not recommended	Not recommended
Cast irons	NI-ROD* alloys 44, 99, NILO* alloy 55	NI-ROD* alloys 44, FC55, NILO* alloy 55	NI-ROD* alloy FC55, INCOFLUX* 5
Steels containing molybdenum	INCONEL* alloy 625	INCONEL* alloy 625	INCONEL* alloy 625, INCOFLUX* 7

Copper and copper alloys

Direct current, electrode negative is used with argon as the shielding gas for copper and most of its alloys with currents up to 400 A. and angle of torch and rod roughly as for aluminium welding. With aluminium bronze and copper–chromium alloys however, dispersal of the oxide film is difficult when using d.c., and for these alloys a.c. is generally used, but d.c. can be used with helium as the shielding gas. The weld areas should be bronze wire brushed and degreased and each run brushed to remove oxide film. Jigs or tack welds can be used for accurate positioning and to prevent distortion.

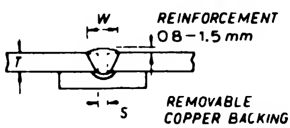
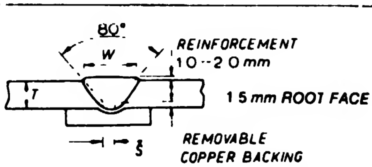
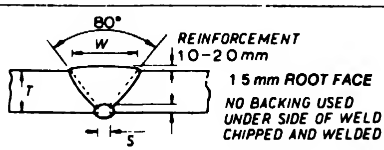
Mild steel or stainless steel backing bars, coated with graphite or anti-

spatter compound to prevent fusion, can be used to control the penetration bead and also to prevent heat dissipation, or backing may be welded into the joint.

Because of the high coefficient of thermal expansion of copper the root gap has a tendency to close up as welding proceeds, and due to its high thermal conductivity pre-heating from 400–700 °C according to thickness is essential on all but the thinnest sections to obtain a good molten pool. The thermal conductivity of most of the copper alloys is much lower than copper so that pre-heating to about 150 °C is usually sufficient. In the range 400–700 °C a reduction in ductility occurs in most of the alloys so that a cooling period should be allowed between runs. The main grades of copper are (1) tough pitch (oxygen containing) high conductivity, (2) oxygen free, high conductivity, (3) phosphorus deoxidized, and in most cases it is the last type that is used for pressure vessels, heat exchangers and food processing equipment, etc. If tough pitch copper, in the cast form, is to be welded, a deoxidizing filler rod should be used to give a deoxidized weld and in all cases the weld should be performed as quickly as possible to prevent overheating.

Argon, helium and nitrogen can be used as shielding gases. Argon has a lower heat output than helium and nitrogen because it has a lower arc voltage. Argon can be mixed with helium and the mixture increases the heat output proportionally with the helium percentage, so that using the mixture for copper welding a lower pre-heat input is required and

Fig. 10.28.

	Nickel alloys Examples of joint design for fusion welding Type of joint	Material thickness (mm) T	Width of groove (top) (mm) W	Root space (mm) S
Square butt		1.0	3.2	0
		1.2	4.0	0
		1.6	4.8	0
		2.4	4.8–6.4	0–0.8
		3.2	6.4	0–0.8
V groove		4.8	8.9	3.2
		6.4	13.0	4.8
		8.0	15.5	4.8
		9.5	18.0	4.8
		12.7	23.0	4.8
		16.0	29.5	4.8
V groove		6.4	10.4	2.4
		8.0	13.0	2.4
		9.5	16.5	3.2
		12.7	21.6	3.2
		16.0	27.0	3.2

penetration is increased. Nitrogen gives the greatest heat output but although the welds are sound they are of rough appearance.

Recommended filler alloys are:

C7 0.05–0.35% Mn, 0.2–0.35% Si, up to 1.0% Sn, remainder Cu.
C8 0.1–0.3% Al, 0.1–0.3% Ti, remainder Cu.
C21 0.02–0.1% B, 99.8% Cu.

Note. Filler alloys for copper and its alloys are to BS 2901, Pt 3, 1970.

Copper–silicon (silicon bronzes). d.c. supply, electrode negative and argon (or helium) shield. These alloys contain about 3% silicon and 1% manganese. They tend to be hot short in the temperature range 800–950°C so that cooling should be rapid through this range. Too rapid cooling, however, may promote weld cracking.

Filler alloy C9, 96% Cu, 3% Si, 1% Mn is recommended.

Copper–aluminium (aluminium bronzes). a.c. with argon shield or d.c. with helium shield. The single phase alloys contain about 7% Al and the two phase alloys up to 11% Al with additions of Fe, Mn and Ni. Welding may affect the ductility of both types. Weld root cracking in the 6–8% Al, 2–2.3% Fe alloy used for heat exchangers can be avoided by using a non-matching filler rod. Due to a reduction in ductility at welding temperatures difficulty may be experienced in welding these alloys. The alloy containing 9% Al and 12% Mn with additions of Fe and Ni has good weldability but requires heat treatment after welding to restore corrosion resistance and other mechanical properties.

Recommended filler alloys are:

C12 6.0–7.0% Al, remainder Cu.
C13 9.0–11.0% Al, remainder Cu.
C20 8.0–10.0% Al, 1.5–3.5% Fe, 4.0–7.0% Ni, remainder Cu.

Copper–nickel (cupro nickels). d.c. with argon shield and electrode negative. These alloys, used for example for pipe work and heat exchangers, contain from 5 to 30% Ni, often with addition of Fe or Mn to increase corrosion resistance. They are very successfully welded by both TIG and MIG processes but since they are prone to contamination by oxygen and hydrogen, an adequate supply of shielding gas must be used including a back purge in certain cases, if possible.

Recommended filler alloys are:

C17 19–21% Ni, 0.2–0.5% Ti, 0.2–1.0% Mn, remainder Cu.
C19 29–31% Ni, 0.2–0.5% Ti, 0.2–1.0% Mn, remainder Cu.

Copper–tin (phosphor bronzes and gunmetal), d.c. with argon shield. The wrought phosphor bronzes contain up to 8% Sn with phosphorus additions

up to 0.4%. Gunmetal is a tin bronze containing zinc and often some lead. Welding of these alloys is most often associated with repair work using a phosphor bronze filler wire but to remove the danger of porosity, non-matching filler wires containing deoxidizers should be used.

Filler alloys recommended are:

C10 4.5–6.0% Sn, 0.4% P, remainder Cu.
C11 6.0–7.5% Sn, 0.4% P, remainder Cu.

Copper–zinc (brass and nickel silvers), a.c. with argon shield, d.c. with helium shield. The copper zinc alloys most frequently welded are Admiralty brass (70% Cu, 29% Zn, 1% Sn), Naval brass (62% Cu, 36.75% Zn, 1.25% Sn) and aluminium brass (76% Cu, 22% Zn, 2% Al). Porosity, due to the formation of zinc oxide, occurs when matching filler wire is used so that it is often preferable to use a silicon–bronze wire which reduces evolution of fumes. This may, however, induce cracking in the HAZ. Post-weld stress relief in the 250–300 °C range reduces the risk of stress corrosion cracking. The range of nickel silver alloys is often brazed.

Filler alloys recommended are:

C14 70–73% Cu, 1.0–1.5% Sn, 0.02–0.06% As.
C15 76–78% Cu, 1.8–2.3% Sn, 0.02–0.06% As.

Work-hardening and precipitation-hardening copper-rich alloys

The work-hardening alloys are not often welded because mechanical properties are lost in the welding operation. Heat-treatable alloys such as copper–chromium and copper–beryllium are welded with matching filler rods using an a.c. supply to disperse the surface oxides. They are usually welded in the solution-treated or in the over-aged condition and then finally heat-treated.

Hardfacing

The tungsten arc is a good method for deposition of stellite and other hard surfacing materials on a base metal. The heat is more concentrated than that of the oxy-acetylene flame and although there may be some base metal pick-up this can be kept to a minimum by using correct technique and there is not a great deal of dilution. It produces a clean, sound deposit and is very useful for reactive base metals.

The electrode is connected to the −ve pole (straight polarity) with the largest diameter filler rod possible to reduce tungsten contamination. Deposition is similar to that when the oxy-acetylene flame is used and deposition moves from right to left. Filler rods of 3.2, 4.0, 4.8, 6.4 and 8 mm are available and alloys include stellite and nickel-based alloys, and

deposition proceeds in the normal way for hard surfacing – do not puddle the pool as this increases dilution.

Easily hardfaced

Low and medium carbon steel to 0.4% C. Above 0.4% C, oxy-acetylene only.

Low-alloy steels.

Nickel and nickel–copper alloys.

Chrome–nickel stainless steels, niobium stabilized. (Not free machining nor titanium stabilized).

11–14% manganese steels.

More difficult to hardface

Cast iron.

Stainless steel, straight and titanium stabilized.

Tool and die steels, water-hardening, oil-hardening and air-hardening types and hot work grade.

Straight chromium stainless steels.

Automatic welding

For automatic welding the TIG torch is usually water cooled and may be carried on a tractor moving along a track or mounted on a boom so as to move over the work or for the work to move under the head. The head has a control panel for spark starter, water and gas and current contactor, and the torch has lateral and vertical movement, the arc length being kept constant by a motor-driven movement controlled by circuits operating from the arc length. Filler wire is supplied from the reel to the weld pool by

TIG process. Recommended filler wires for copper welding

Type (BS 2870 2875)	Grade	Filler wire: Argon or helium shield	Filler wire: Nitrogen shield
C106	Phosphorus deoxidized non-arsenical	C7, C21	C8
C107	Phosphorus deoxidized arsenical		
C101	Electrolytic tough pitch high conductivity	C7, C21	Not recommended
C102	Fire-refined tough pitch high conductivity		
C103	Oxygen-free high conductivity	C7, C21	Not recommended

rollers driven by an adjustable speed motor. Heavier currents can be used than with manual operation resulting in greater deposition rates, and the accurate control of speed of travel and arc length results in welds of high quality. Plate up to 9 mm thick can be welded in one run, the welding being of course downhand. Fig. 10.29 illustrates a typical tractor-driven head.

Orbital pipe welding unit

This can operate from a standard TIG power source and enables circumferential joints on pipes and tubes to be made automatically. It is of caliper type enabling rapid adjustments to be made, and rotational drive is by a small motor mounted in the handle of the unit, rotational speed being controlled by transistor regulator. A wire feed unit feeds wire to the arc, the feed speed of the wire being controlled by a thyristor regulator. Three sizes are available for pipes with outside diameters of 18–40, 36–80 and 71–160 mm (Fig. 10.30).

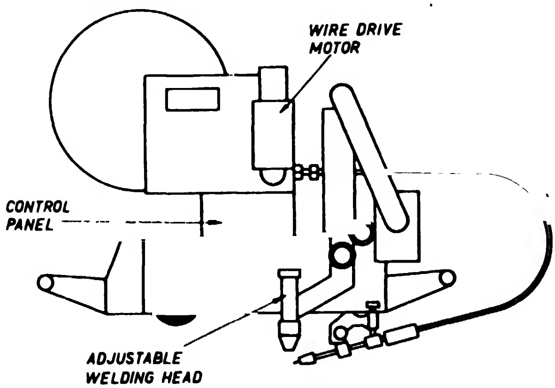
Mechanized TIG hard facing

In this process the argon shielded TIG arc oscillates over a width from 6 to 25 mm and is operated by variable controls for speed and width. Rod and torch also have controls for vertical height and horizontal positioning and for feeding the hard surfacing rod.

Small quantities of hydrogen are added to the argon by means of a gas blender to give a more consistent deposit. The stellite alloy, in rod form, can be laid on large circular components of 100–600 mm diameter and this is ideal for valves and valve seatings, rings and sleeves, etc., the work being mounted on a manipulator.

A smaller system enables components from 25–220 mm diameter to be hard faced. The unit can be adapted for flat straight working if required and the usual power unit for TIG welding is required. A complete range of hard facing alloys is available.

Fig. 10.29. Automatic TIG welding head mounted on electrically driven tractor; 500 A water cooled torch.



TIG robot welding

TIG welding has now been applied to the robot system with two manipulators. In this method of welding the workpieces are held in jigs on the plates of the manipulators, one being welded while the other is being loaded. The six axes of the robot enable it to handle the filler wire and place it in the best position without limitation of the wrist movement of the robot.

Since the HF necessary for the arc initiation may cause unwanted signals to the microprocesser all conductors have been screened. The control computer selects and records the particular welding program and together with the robot achieves synchronized movements, and welding operations are commenced when the operator has loaded one of the two manipulators of the system. (See Chapter 12, Welding with robots, for illustration of this system.)

Various parameter sequences for various operations can be pre-recorded and recalled as required.

Spot welding

Mild steel, stainless and alloy steel and the rarer metals such as titanium can be spot welded using a TIG spot welding gun. The pistol grip water cooled gun carries a collet assembly holding a thoriated tungsten electrode positioned so that the tip of the electrode is approximately 5 mm

Fig. 10.30. Orbital TIG pipe welding.

within the nozzle orifice, thus determining the arc length. Interchangeable nozzles enable various types of joints to be welded flat, or vertically. A variable timing control on the power unit allows the current to be timed to flow to ensure fusion of the joint and a switch on the gun controls gas, water, HF unit and current contactor. To make a weld, the nozzle of the gun is pressed on to the work in the required position and when the gun switch is pressed the following sequence occurs: (1) gas and water flow to the gun, (2) the starter ignites the arc and the current flows for a period controlled by the timer, (3) current is automatically switched off and post-weld argon flows to cool electrode tip and weld.

Note. Refer also to BS 3019, *General recommendations for inert gas, tungsten arc welding*, Part 1: *Wrought aluminium, aluminium alloys and magnesium alloys*, Part 2: *Austenitic stainless and heat resisting steels.*

Titanium

Titanium is a silvery coloured metal with atomic weight 47.9, specific gravity 4.5 (cf. Al 2.7 and Fe 7.8) melting point 1800°C and UTS 310 N/mm^2 in the pure state. It is used as deoxidizer for steel and sometimes in stainless steel to prevent weld decay and is being used in increasing amounts in the aircraft and atomic energy industries because of its high strength-to-weight ratio.

Titanium absorbs nitrogen and oxygen rapidly at temperatures above 1000°C and most commercial grades contain small amounts of these gases; the difficulty in reducing the amounts present makes titanium expensive. Because of this absorption it can be seen that special precautions have to be taken when welding this metal.

Where seams are reasonably straight a TIG torch with tungsten electrode gives reasonable shrouding effect on the upper side of the weld, and jigs may be employed to concentrate the argon shroud even more over the weld. In addition the underbead must be protected and this may be done by welding over a grooved plate, argon being fed into this groove so that a uniform distribution is obtained on the underside. It can be seen therefore that the success of welding in these conditions depends upon the successful shrouding of the seam to be welded.

For more complicated shapes a vacuum chamber may be employed. The chamber into which the part to be welded is placed is fitted with hand holes, and over these are bolted long-sleeve rubber gloves into which the operator places his hands, and operates the TIG torch and filler rod inside the chamber. An inspection window on the sloping top fitted with welding glass enables a clear view to be obtained. All cable entries are sealed tightly and the air is extracted from the chamber as completely as possible by pumps,

and the chamber filled with argon, this being carried out again if necessary to get the level of oxygen and nitrogen down to the lowest permissible level. The welding may be performed with a continuous flow of argon through the chamber or in a static argon atmosphere. Since the whole success of the operation depends upon keeping oxygen and nitrogen levels down to an absolute minimum great care must be taken to avoid leaks as welding progresses and to watch for discoloration of the weld indicating absorption of the gases.

Tantalum

Tantalum is a metallic element of atomic weight 180.88, HV 45, melting point 2910°C, specific gravity 16.6, it is a good conductor of heat and is used in sheet form for heat exchangers, condensers, small tubes, etc. Like titanium it readily absorbs nitrogen and oxygen at high temperatures and also readily combines with other metals so that it is necessary to weld it with a TIG torch in a vacuum-purged argon chamber as for titanium.

Beryllium

Beryllium is a light, steely coloured metallic element, atomic weight 9, melting point 1280–1300°C, specific gravity 1.8, HV 55–60. It is used as an alloy with copper (beryllium bronze) to give high strength with elasticity. As with tantalum and titanium it can be welded in a vacuum-purged argon chamber using a TIG torch. It can also be pressure welded and resistance welded.

Electron beam welding is now being applied to the welding of the rare metals such as the foregoing, in the vacuum chamber. A beam of electrons is concentrated on the spot where the weld is required. The beam can be focused so as to give a small or large spot, and the power and thus the heating effect controlled. Successful welds in a vacuum-purged argon chamber are made in beryllium and tantalum.

*Plasma-arc welding (plasma welding)**

Plasma welding is a process which complements, and in some cases is a substitute for, the TIG process, offering, for certain applications, greater welding speed, better weld quality and less sensitivity to process variations. The constricted arc allows lower current operation than TIG for similar joints and gives a very stable controllable arc at currents down to 0.1 A, below the range of the TIG arc, for welding thin metal foil sections. Manual plasma welding is operated over a range 0.1–100 A from

* American designation: plasma-arc welding (PAW).

foil to 3–4 mm thickness in stainless steel, nickel and nickel alloys, copper, titanium and other rare earth metals (not aluminium or magnesium).

Ions and plasma

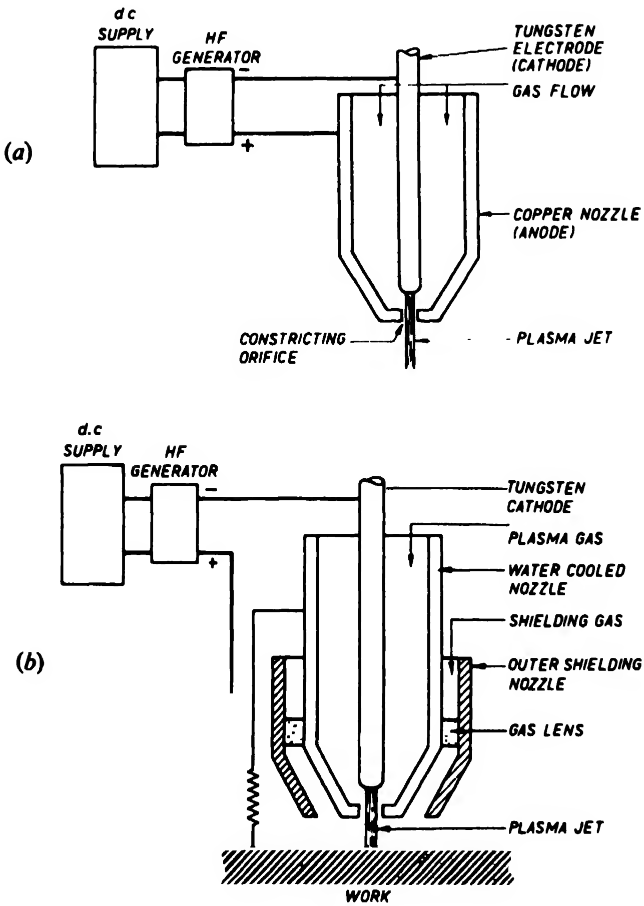
An ion is an atom (or group of atoms bound into a molecule) which has gained or lost an electron or electrons. In its normal state an atom exhibits no external charge but when transference of electrons takes place an atom will exhibit a positive or negative charge depending upon whether it has lost or gained electrons. The charged atom is called an ion and when a group of atoms is involved in this transference the gas becomes ionized.

All elements can be ionized by heat to varying degrees (thermal ionization) and each varies in the amount of heat required to produce a given degree of ionization, for example argon is more easily ionized than helium. In a mass of ionized gas there will be electrons, positive ions and neutral atoms of gas, the ratio of these depending upon the degree of ionization.

A plasma is the gas region in which there is practically no resultant charge, that is, where positive ions and electrons are equal in number; the region is an electrical conductor and is affected by electric and magnetic fields. The TIG torch produces a plasma effect due to the shield of argon and the tungsten arc but a plasma jet can be produced by placing a tungsten electrode centrally within a water-cooled constricted copper nozzle. The tungsten is connected to the negative pole (cathode) of a d.c. supply and the nozzle to the positive pole (anode). Gas is fed into the nozzle and when an arc is struck between tungsten electrode and nozzle, the gas is ionized in its passage through the arc and, due to the restricted shape of the nozzle orifice, ionization is greatly increased and the gas issues from the nozzle orifice, as a high-temperature, high-velocity plasma jet, cylindrical in shape and of very narrow diameter realizing temperatures up to 10000°C. This type is known as the non-transferred plasma (Fig. 10.31*a*). With the transferred arc process used for welding, cutting and surfacing, the restricting orifice is in an inner water-cooled nozzle within which the tungsten electrode is centrally placed. Both work and nozzle are connected to the anode and the tungsten electrode to the cathode of a d.c. supply (in American terms, d.c.s.p., direct current straight polarity). Relatively low plasma gas flow (of argon, argon–helium or argon–hydrogen) is necessary to prevent turbulence and disturbance of the weld pool, so a further supply of argon is fed to the outer shielding nozzle to protect the weld (Fig. 10.31*b*). In the lead from work to power unit there is a contactor switch as shown.

A high-frequency unit fed from a separate source from the mains supply initiates the pilot arc and the torch nozzle is positioned exactly over the work. Upon closing the contactor switch in the work-to-power unit connexion, the arc is transferred from electrode to work via the plasma. Temperatures up to 17000 °C can be obtained with this arc. To shape the arc two auxiliary gas passages on each side of the main orifice may be included in the nozzle design. The flow of cooler gas through these squeezes the circular pattern of the jet into oval form, giving a narrower heat-affected zone and increased welding speed. If a copper electrode is used instead of tungsten as in the welding of zirconium, it is made the anode. The low-current arc plasma with currents in the range 0.1- 15 A has a longer operating length than the TIG arc, with much greater tolerance to change

Fig. 10.31. (*a*) Non-transferred plasma arc. (*b*) Transferred plasma arc.



in arc length without significant variation in the heat energy input into the weld. This is because it is straight, of narrow diameter, directional and cylindrical, giving a smaller weld pool, deeper penetration and less heat spread whereas the TIG arc is conical so that small changes in arc length have much more effect on the heat output. **Fig. 10.32** compares the two arcs. Since the tungsten electrode is well inside the nozzle (about 3 mm) in plasma welding, tungsten contamination by touchdown or by filler rod is avoided, making welding easier.

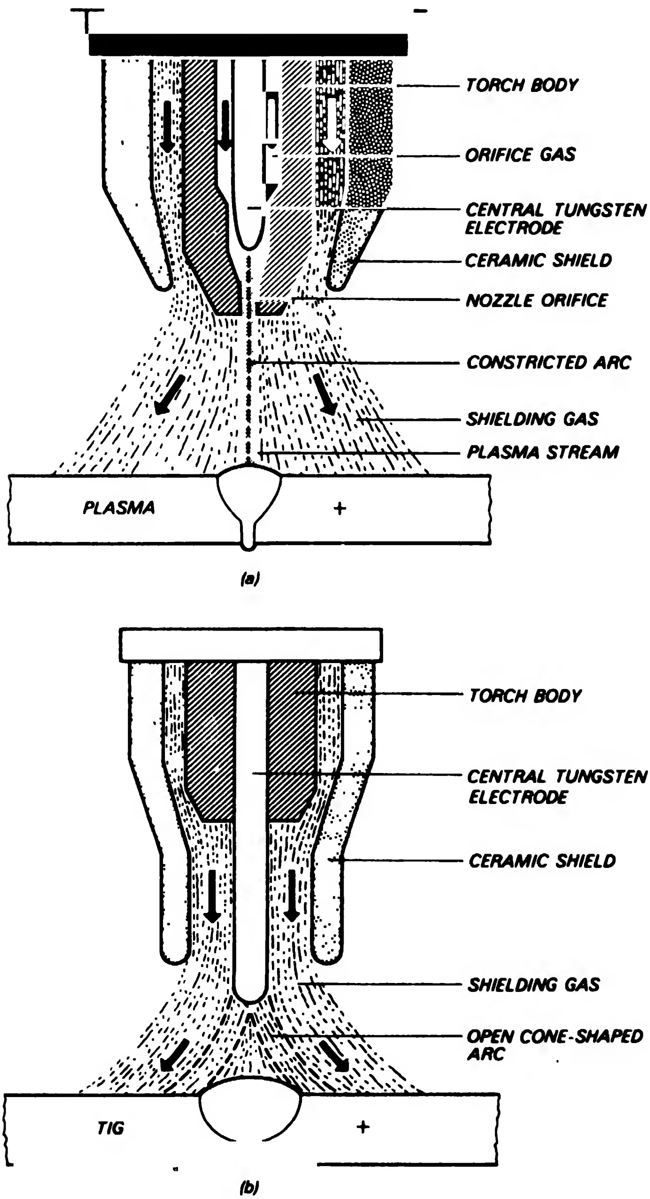
Equipment. In the range 5–200 A a d.c. rectifier power unit with drooping characteristic and an OCV of 70 V can be used for argon and argon–hydrogen mixtures. If more than 5% hydrogen is used, 100 V or more is required for pilot arc ignition. This arc may be left in circuit with the main arc to give added stability at low current values. Existing TIG power sources such as that in **Fig. 10.11** may be used satisfactorily, reducing capital cost, the extra equipment required being in the form of a console placed on or near the power unit. Input is 380–440 V, 50 Hz, a.c. single-phase with approximately 3.5 A full load current. It houses relays and solenoid valves controlling safety interlocks to prevent arc initiation unless gas and water pressures are correct; flowmeters for plasma and shielding gases, gas purge and post-weld gas delay and cooling water controls. For low-current welding in the range 0.1–15 A, often referred to in Europe as micro-plasma and in America as needle plasma welding, the power unit is about 3 KVA, 200–250 V, 50 Hz single-phase input, fan cooled with OCV of 100 V nominal and 150 V peak d.c., for the main arc, and output current ranges 0.1–2.0 A and 1.0–15 A. The pilot arc takes 6A at 25 V start and 2.5 A at 24 V running, the main arc being cylindrical and only 0.8 mm wide. Tungsten electrodes are 1.6, 2.4 and 3.2 mm diameter, depending upon application.

Gases. Very pure argon is used for plasma and shield (or orifice) when welding reactive metals such as titanium and zirconium which have a strong affinity for hydrogen. For stainless steel and high-strength nickel alloys argon, or argon–hydrogen mixtures are used. Argon–5% hydrogen mixtures are applied for this purpose (cylinders coloured blue with a wide red band around the middle) and argon–8% hydrogen and even up to 15% hydrogen are also used. With these mixtures the arc voltage is increased giving higher welding speeds (up to 40% higher) and the thin oxide film present even on stainless and alloy steels is removed by hydrogen reduction giving a clean bright weld, and the wetting action is improved. For copper, nickel and their alloys argon is used in keyhole welding (**Fig. 10.33**) for thinner sections, for both orifice and shielding gas. Argon and helium is

used in the melt-in welding of thinner sections and helium for orifice and shielding gas for sections over 3 mm thick.

De-ionized cooling water should be used, and gas flow rates at 2.0 bar pressure are about 0.25–3.3 litres per minute plasma and 3.8–7 litres per minute shielding in the 5–100 A range. Cleaning and preparation are

Fig. 10.32. (*a*) Plasma arc. (*b*) TIG arc.



similar to those for TIG, but when welding very thin sections, oil films or even fingerprints can vary the degree of melting, so that degreasing should be thorough and the parts not handled in the vicinity of the weld after cleaning.

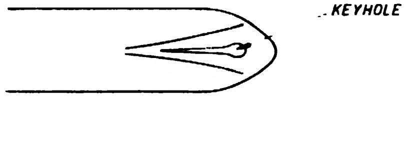
Technique. Using currents of 25–100 A, square butt joints in stainless steel can be made in thicknesses of 0.8–3.2 mm with or without filler rod, the angle of torch and rod being similar to that for TIG welding. The variables are current, gas flow and welding rate. Too high currents may break down the stabilizing effect of the gas, the arc wanders and rapid nozzle wear may occur. In 'double arcing' the arc extends from electrode to nozzle and then to the work. Increasing plasma gas flow improves weld appearance and increases penetration, and the reverse applies with decreased flow. A turbulent pool gives poor weld appearance.

In 'keyhole' welding of thicknesses of 2.5–6.5 mm a hole is formed in the square-edge butt joint at the front edge of the molten pool, with the arc passing through the section (Fig. 10.33). As the weld proceeds, surface tension causes the molten metal to flow up behind the hole to form the welding bead, indicating complete penetration, and gas backing for the underbead is required. When butt welding very thin sections, the edges of the joint must be in continuous contact so that each edge melts and fuses into the weld bead. Separation of the edges gives separate melting and no weld. Holding clamps spaced close together near the weld joint and a backing bar should be used to give good alignment, and gas backing is recommended to ensure a fluid pool and good wetting action. Flanging is recommended for all butt joints below 0.25 mm thickness and allows for greater tolerance in alignment. In the higher current ranges joints up to 6 mm thick can be welded in one run. Lap and fillet welds made with filler rod are similar in appearance and employ a similar technique to those made with the manual TIG process. Edge welds are the best type of joint for foil thickness, an example being a plug welded into a thin-walled tube.

In tube welding any inert gas can be used within the tube for underbead protection.

Faults in welding very thin sections are: excessive gaps which the metal cannot bridge; poor clamping allowing the joint to warp; oil films varying the degree of melting; oxidation or base metal oxides preventing good

Fig. 10.33. Surface tension causes molten metal to flow and close keyhole



'wetting'; and nicking at the ends of a butt joint. This latter can be avoided by using run-off plates or by using filler rod for the start and finish of the weld.

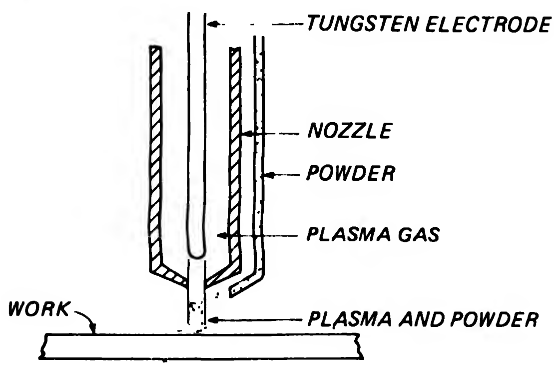
Plasma spray hard facing

In this method the arc plasma melts the hard facing powder particles and the high-velocity gas stream carries the molten particles on to the surface (Fig. 10.34). Although there may be some voids caused, 90–95% densities can be obtained and the method is particularly suitable for applying refractory coatings because this method has a better bond with the parent plate than the spray and fuse method. Because the heat is localized, surfaces can be applied to finished parts with no distortion and the finish is very smooth. The cobalt, nickel- and tungsten-based powders are all supplied for this process and suitable applications are gas turbine parts, such as sealing rings of gas turbines, mixer and feed parts, sleeves, sheets and wear pads and slides, etc.

Plasma transferred arc hardfacing

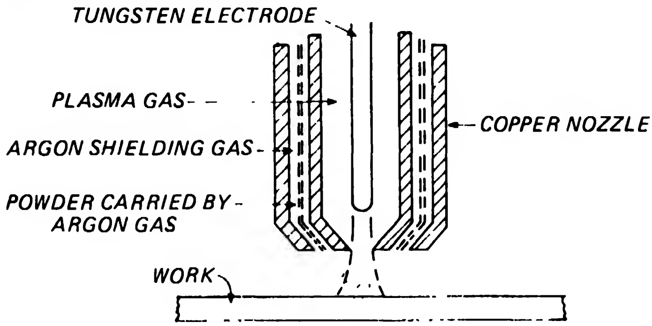
This powder deposition process is fully automated and uses a solid state SCR, the power output being 300 A, 32 V, at 100% duty cycle. The pilot arc is initiated by HF and the unit has pulse facilities. The powder is supplied from a powder feeder operating on the rotating drum principle. Powder feed rate is controlled by varying the feed opening over the knurled rotating wheel upon which a regulated ribbon of powder is applied, and the powder feed can be regulated to provide an upslope and downslope feed rate. This powder is carried from the container to the work in a stream of argon and is melted in the plasma, the argon providing a shield around the plasma heat zone (Fig. 10.35). Torches are of varying size and cover most

Fig. 10.34. Plasma surfacing.



hard surfacing requirements. As can be seen in the illustration the plasma and powder are supplied through separate passages. Cobalt-based (stellite), nickel-based, iron-based with chrome or molybdenum alloys are available and applications include valve seats, oil drill tool joints, gate valve inserts, diesel engine crossheads, etc. Stellite alloys Nos. 1, 6, 12, 21, 156, 157, 158, F of the stellite range are suitable.

Fig. 10.35. Plasma transferred arc



11

Resistance welding and flash butt welding

Spot welding

In this method of welding use is made of the heating effect which occurs when a current flows through a resistance. Suppose two steel plates A and B (Fig. 11.1) are to be welded together at X. Two copper electrodes are pressed against the plates squeezing them together. The electrical resistance is greatest at the interface where the plates are in contact, and if a large current at low voltage is passed between the electrodes through the plates, heat is evolved at the interface, the heat evolved being equal to I^2Rt joules, where I is the current in amperes, R the resistance in ohms and t the time in seconds. A transformer supplies a.c. at low voltage and high current to the electrodes (Figs. 11.1 and 11.2).

Fig. 11.1

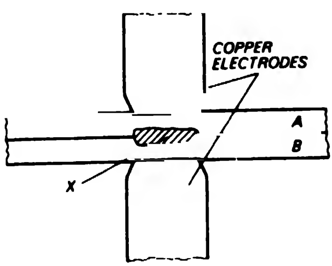
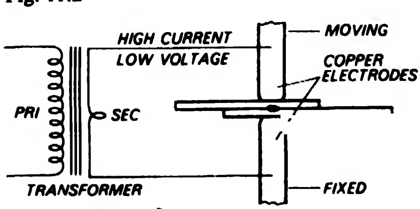


Fig. 11.2



For any given joint between two sheets a suitable time is selected and the current varied until a sound weld is obtained. If welds are made near each other some of the current is shunted through the adjacent weld (Fig. 11.3) so that a single weld is not representative of what may occur when several welds are made. Once current and time are set, other welds will be of consistent quality. If the apparatus is controlled by a pedal as in the simplest form of welder, then pressure is applied mechanically and the time for which the current flows is switch controlled, as for example in certain types of welding guns used for car body repairs. This method has the great disadvantage that the time cannot be accurately controlled, so that if it is too short there is insufficient heat and there is no fusion between the plates, whilst if the time is too long there is too much heat generated and the section of the plates between the electrodes melts, the molten metal is spattered out due to the pressure of the electrodes and the result is a hole in the plates. In modern spot-welding machines the pressure can be applied pneumatically or hydraulically or a combination of both and can be accurately controlled. The current is selected by a tapping switch on the primary winding of the transformer and the time is controlled electronically, the making and breaking of the circuit being performed by thyristors.

When the current flows across the interface between the plates, the heating effect causes melting and fusion occurs at *A* (Fig. 11.4). Around this there is a narrow heat-affected zone (HAZ) since there is a quenching effect

Fig. 11.3

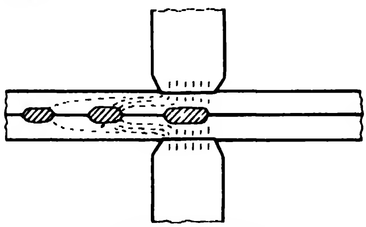
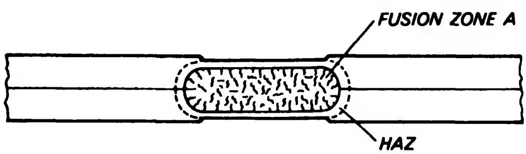


Fig. 11.4



due to the electrodes, which are often water cooled. There are equi-axed crystals in the centre of the nugget and small columnar crystals grow inwards towards the centre of greatest heat.

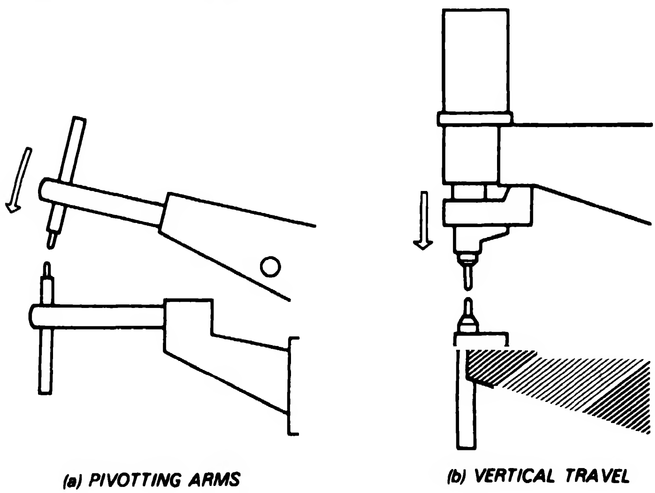
Types of spot welders

In the pedestal type there is a fixed vertical pedestal frame and integral transformer and control cabinet. The bottom arm is fixed to the frame and is stationary during welding and takes the weight of the workpiece. The top arm may be hinged so as to move down in the arc of a circle (Fig. 11.5*a*) or it may be moved down in a straight line (Fig. 11.5*b*). Pivoting arms are adjustable so as to have a large gap between the electrodes, the arms are easily adjusted in the hubs and various length arms are easily fitted giving easy access to difficult joints. The vertical travel machine has arms of great rigidity so that high pressures can be applied, and the electrode tips remain in line irrespective of the length of stroke, so that the machine is easily adapted for projection welding. Additionally the spot can be accurately positioned on the work, and since the moving parts have low inertia, high welding speeds can be achieved without hammering (see Fig. 11.6*a* and *b*).

Welding guns

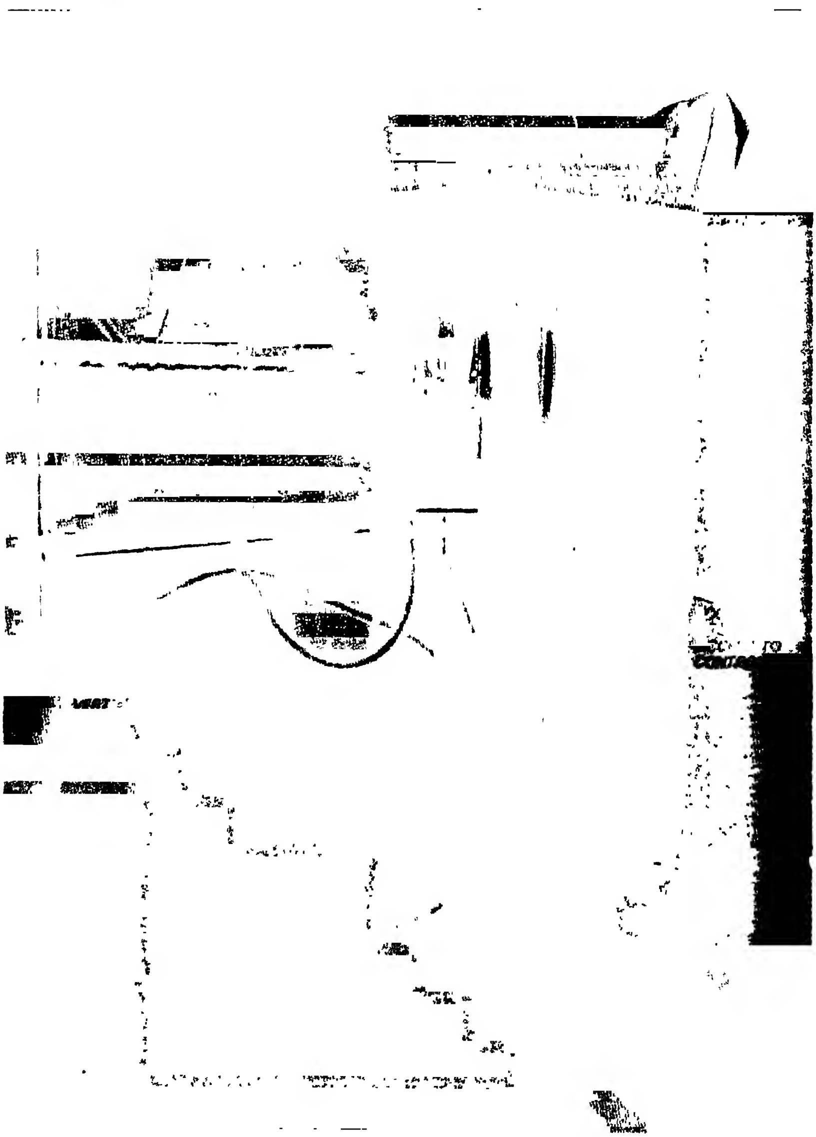
Portable welding guns are extensively used in mass production. The equipment consists of the welding station often with hydro-pneumatic booster to apply the pressures, a water manifold, one or two welding guns

Fig. 11.5. (*a*) Pivoting arms, (*b*) vertical travel.



with balancers, cable between transformer and guns and a control station. In modern machines the composite station with built-in cabinet comprises sequence controls with integrated circuits, thyristor contactors and disconnect switch. Articulated guns (Figs 11.7*a* and *b*) have both arms articulated as in a pair of scissors, giving a wide aperture between electrodes, and are used for welding joints difficult of access. Small

Fig. 11.6. (*a*) Air-operated spot welding machine with pivoting arms.



articulated guns are used for example in car body manufacture for welding small flanges, and in corners and recesses. C guns (Fig. 11.7*c*) have the piston-type ram of the pressure cylinder connected to the moving electrode, which thus moves in a straight line. There is great rigidity and a high working speed because of the low inertia of the moving parts. The electrodes are always parallel and the precision motion is independent of

Fig. 11.6. (*b*) Air-operated spot welding machine with vertical action.

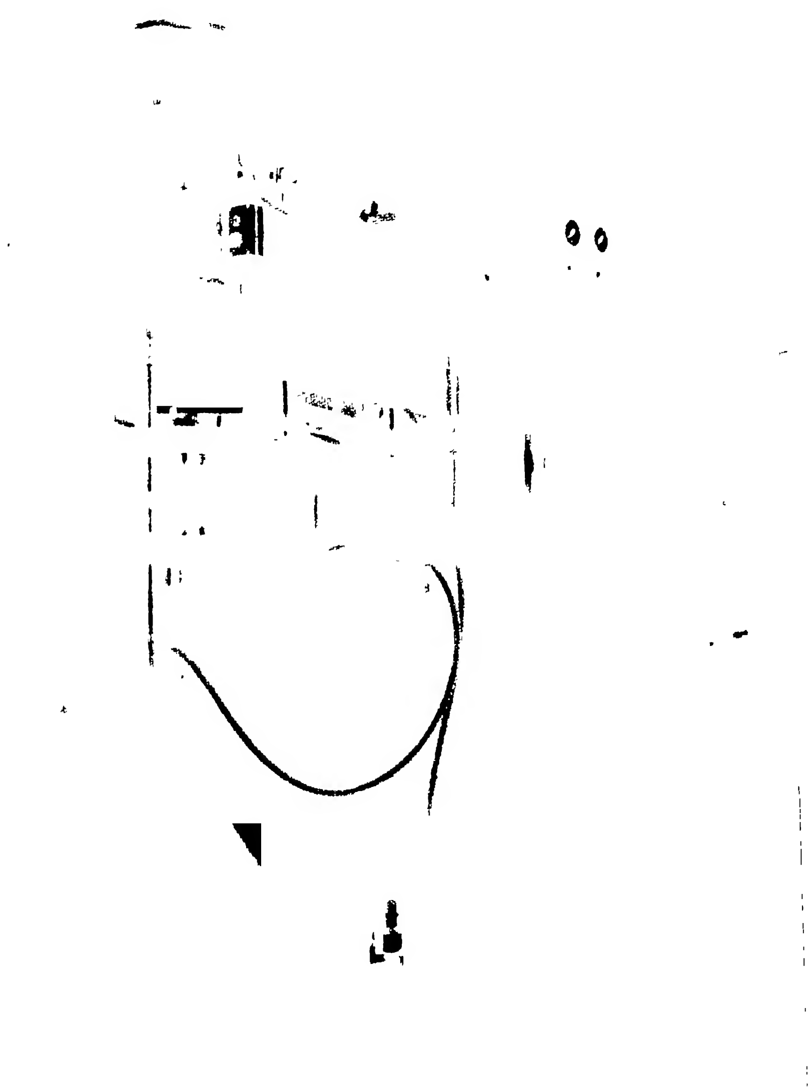


Fig. 11.7. (*a*) Articulated type welding head; air operated.

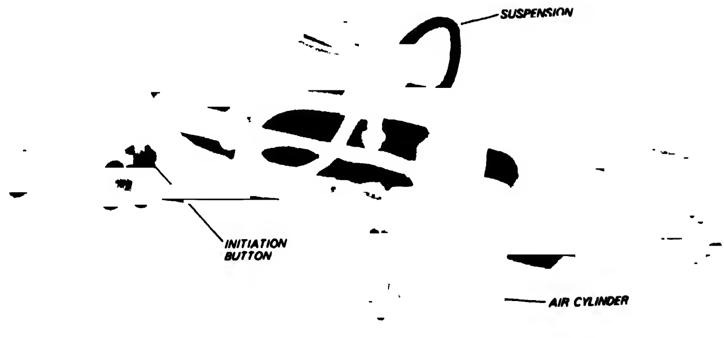


Fig. 11.7. (*b*) Articulated type welding head; hydraulically operated.

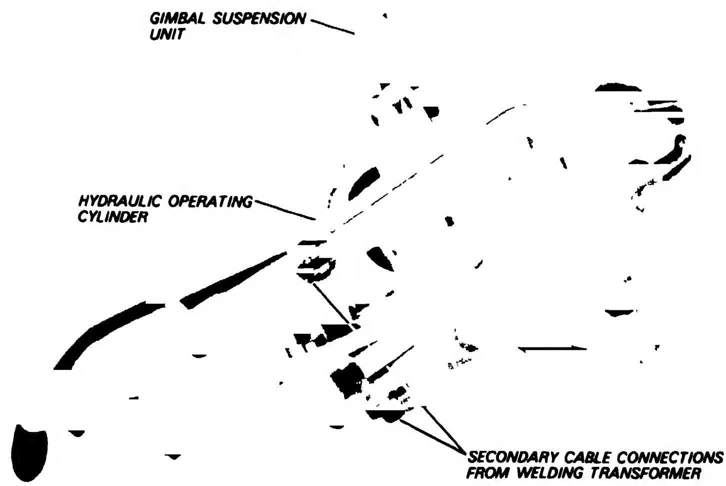
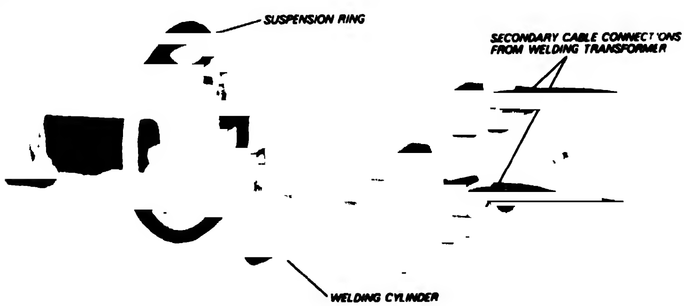


Fig. 11.7. (*c*) Air-operated C type welding head



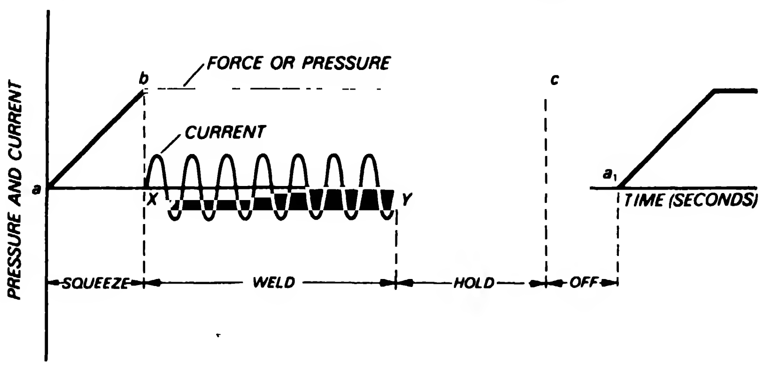
the arm length with easily determined point of welding contact. They are used for quality welds where the height does not preclude them. Integral transformer guns are used to reduce handling costs of bulky fabrications, and the manual air-cooled gun and twin spot gun are used in repair work on car bodies and agricultural equipment and for general maintenance, the latter being used where there is access for only one arm as in closed box sections and car side panels.

The welding cycle

The cycle of operations of most modern machines is completely automatic. Once the hand or foot switch is pressed, the cycle proceeds to completion, the latest form having digital sequence controls with printed circuits, semi-conductors, digital counting and air valve operation by relays. The simplest cycle has one function, namely weld time, the electrode force or pressure being pre-set, and it can be best illustrated by two graphs, one the electrode pressure plotted against time and the other the current plotted against the same time axis (Fig. 11.8). The time axis is divided into 100 parts corresponding to the 50 Hz frequency of the power supply. Fig. 11.8 shows a simple four-event control. First the squeeze is applied and held constant (*a–b* on the graph). The current is switched on at *X*, held for seven complete cycles (7/50 s) and switched off at *Y*. The pressure is held until *c* on the graph, the weld cooling in this period. Finally the squeeze is released and the repeat cycle of operations begins again at a_1. The switches comprise repeat–non-repeat, thyristors on–off and heat control in–out.

For more complex welding cycles, necessary when welding certain metals to give them correct thermal treatment, the graphs are more complex with up to ten functions with variable pressure cycle, and these machines are often operated from three phases. Machines for the aeronautical and space industries are specially designed and incorporate variable pressure heads

Fig. 11.8. Standard four-event sequence for spot welding.



and up to ten functions. Most aluminium alloys lose the properties given to them by work hardening or heat treatment when they are heated. To enable the correct thermal treatment of heating and cooling to be given to them during the welding cycle three-phase machines are often employed.

The transformer

The transformer steps the voltage down from that of the mains to the few volts necessary to send the heavy current through the secondary welding circuit. When the current is flowing the voltage drop across the secondary may be as low as 3–4 volts and in larger machines the current can be up to 35000 A. Because of these large currents there is considerable force acting between the conductors due to the magnetic field, so transformers must be robustly constructed or movement may cause breakdown of the insulation, and in addition they may be water cooled because of the heating effect of the current. The secondary winding consists of one or two turns of copper strip or plates over which the primary coils fit, the whole being mounted on the laminated iron core. Because any infiltration of moisture may lead to breakdown, modern transformers have the primary winding and secondary plates assembled as a unit which is then vacuum encapsulated in a block of epoxy resin. The primary winding has tappings which are taken to a rotary switch which selects the current to be used.

The current flowing in the secondary circuit of the transformer provides the heating effect and depends upon (1) the open circuit voltage and (2) the impedance of the circuit, which depends upon the gap, throat depth and magnetic mass introduced during welding and the resistance of the metal to be welded. The duty cycle is important, as with all welding machines, as it affects the temperature rise of the transformer. For example, if a spot welder is making 48 spot welds per minute, each of 0.25 seconds duration, the duty cycle is $(48 \times 0.25 \times 100) \div 60 = 20\%$. Evidently knowing the duty cycle and welding time, the number of welds that can be made per minute can be calculated.

Electrodes

The electrode arms and tips (**Fig. 11.9*a***) which must carry the heavy currents involved and apply the necessary pressure must have the following properties: (1) high electrical conductivity so as to keep the I^2R loss (the heating due to the resistance) to a minimum, (2) high thermal conductivity to dissipate any heat generated, (3) high resistance to deformation under large squeeze pressures, (4) must keep their physical properties at elevated temperatures, (5) must not pick up metal from the surface of the workpiece,

Electrode	Properties	Uses
(1) Copper, 1% silver	High conductivity, medium hardness.	Light alloys, coated sheets, scaly steel.
(2) Copper, 0.6% Cr or 0.5% Cr and Be	Best electrical conductivity with greatest hardness.	Clean or lightly oxidized steel, brass and cupro-nickel. Used for the arms of the machine and electrical conductors.
(3) Copper, 2.5% Co and 0.5% Be	Poor conductivity but very hard.	For welding hard metals with high resistivity, e.g. stainless steel, heat-resistant and special steels.
(4) Copper, beryllium	Poor conductivity, great hardness.	For clamping jaws of flash butt welders.
(5) Molybdenum		Drawn bar or forged buttons used as pressed fit inserts in supports of (2) above. For welding thin sheet or wires or electro-brazing silver-based metals.
(6) Sintered copper-tungsten	Fair conductivity, very hard.	Keeps its mechanical properties when hot.

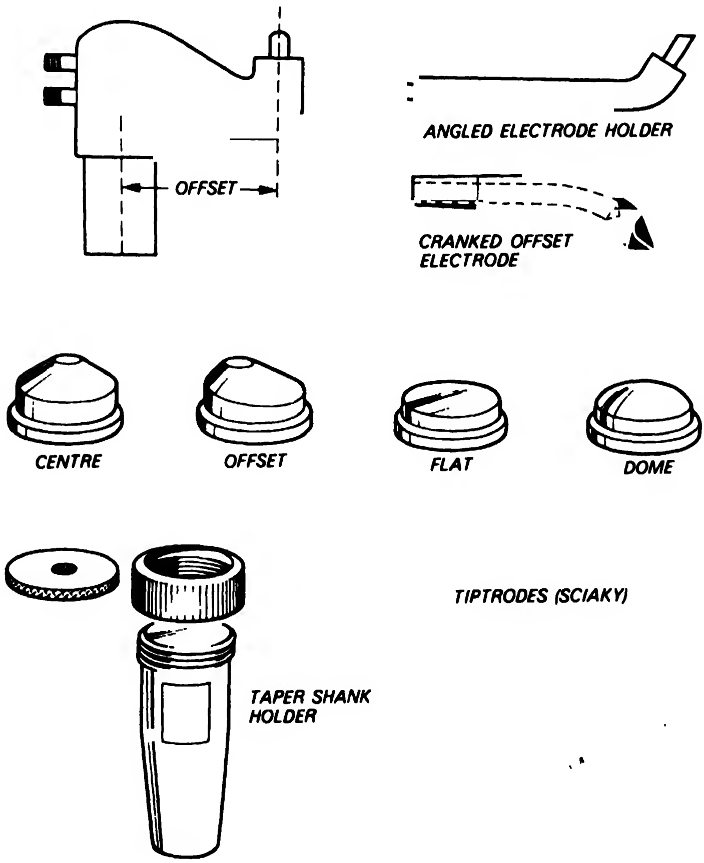
Note. The addition of various elements increases the hardness but reduces the conductivity.

(6) must be of reasonable cost. The following types of electrodes are chiefly used, and are given in the table. Electrolytic copper (99.95% Cu) has high electrical and thermal conductivity and, when work hardened, resists deformation but at elevated temperatures that part of the electrode tip in contact with the work becomes annealed due to the heating and the tip softens and deforms. Because of this it is usual to water-cool the electrodes to prevent excessive temperature rise.*

Water cooling

Adequate electrode cooling is the most essential factor to ensure optimum tip life; the object is to prevent the electrode material from reaching its softening temperature, at which point it will lose its hardness

Fig. 11.9. (*a*) Electrodes and holders.

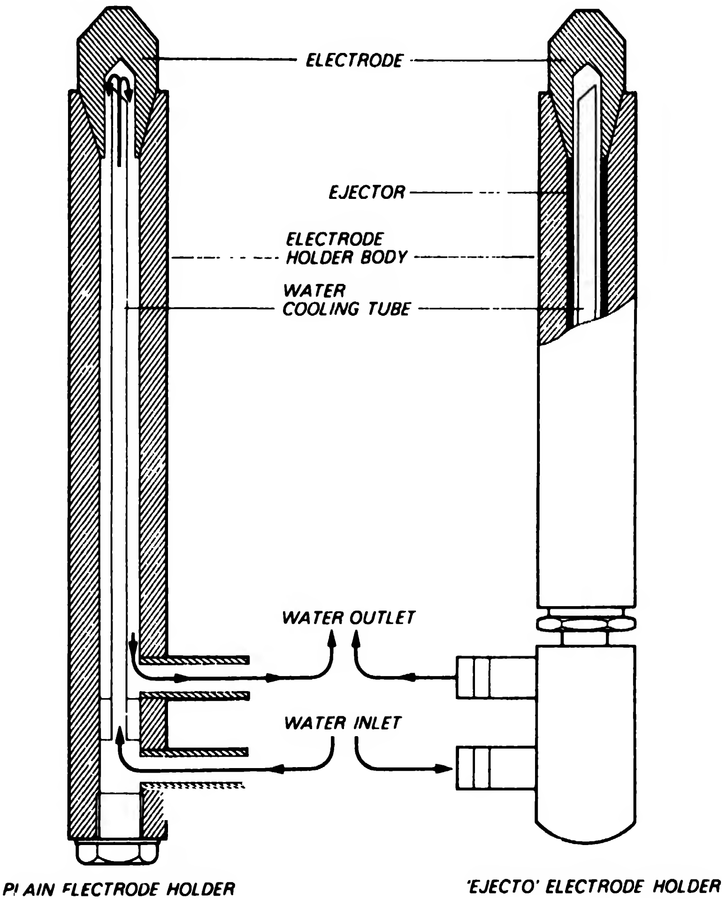


* See also BS 807 and BS 4215 Spot welding electrodes and electrode holders.

and rapidly deteriorate. The normal cooling method is by internal water circulation where the water is fed via a central tube arranged to direct the water against the end of the electrode cooling hole (Fig. 11.9*b*). In some cases a short telescopic extension tube is used inside the main tube and must be adjusted to suit the length of the electrode used.

Electrodes are available with a taper fit to suit the electrode arms and also as tips to fit on to a tapered shank body, which makes them easily interchangeable. The face that makes contact with the metal to be welded can be a truncated cone with central or offset face, flat or domed (Fig. 11.9) and tip diameters can be calculated from formulae which depend upon the plate thickness, but in all cases these are approximate only and do not replace a test on the actual part. Electrodes are subject to great wear and tear in service due to the constant heating and cooling and varying pressure

Fig. 11.9. (*b*)



cycles. The chief causes of wear are: electrical; wrong electrode material, poor surface being welded, contacts not in line; mechanical; electrode hammering, high squeeze, weld and forge pressures, abrasion in loading and unloading and tearing due to the parting of the electrodes.

Seam welding

In a seam welding machine the electrodes of a spot welder are replaced by copper alloy rollers or wheels which press on the work to be welded (Fig. 11.10*a* and *b*). Either one or both are driven and thus the work passes between them. Current is taken to the wheels through the rotary bearings by silver contacts with radial pressure and the drive may be by knurled wheel or the more usual shaft drive which enables various types of wheel to be easily fitted. If the current is passed continuously a continuous seam weld results but, as there is a shunt effect causing the current to flow through that part of the weld already completed, overheating may occur resulting in burning of the sheets. To avoid this the current can be pulsed, allowing sufficient displacement of the already welded portion to take place and thus obviating most of the shunt effect. For materials less than 0.8 mm thick or at high welding speeds (6 m/min) no pulsing is required, the 50 Hz frequency of the supply providing a natural pulse. Above 2 × 0.8 mm thickness pulsation is advisable, and essential above 2 × 1.5 mm thickness, while for pressure-tight seams the welds can be arranged to overlap and if the seams are given a small overlap with wide-faced wheels and high pressure a mash weld can be obtained.

By the use of more complex electro-mechanical bearing assemblies, longitudinal and circumferential welds can be made (Fig. 11.10*c*).

Seam welding guns are extremely useful for fabricating all types of tanks, exhaust systems, barrels, drip-mouldings on car body shells, etc. They have electrode drive which automatically propels the gun along the seam so that

Fig. 11.10. (*a*)

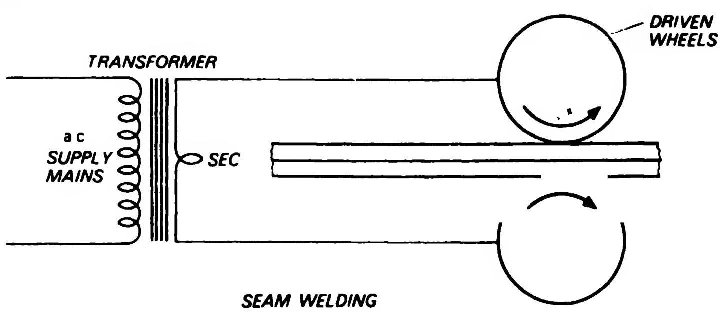


Fig. 11.10. (*b*) 'Thin wheel' seam welding machine with silver bearings.

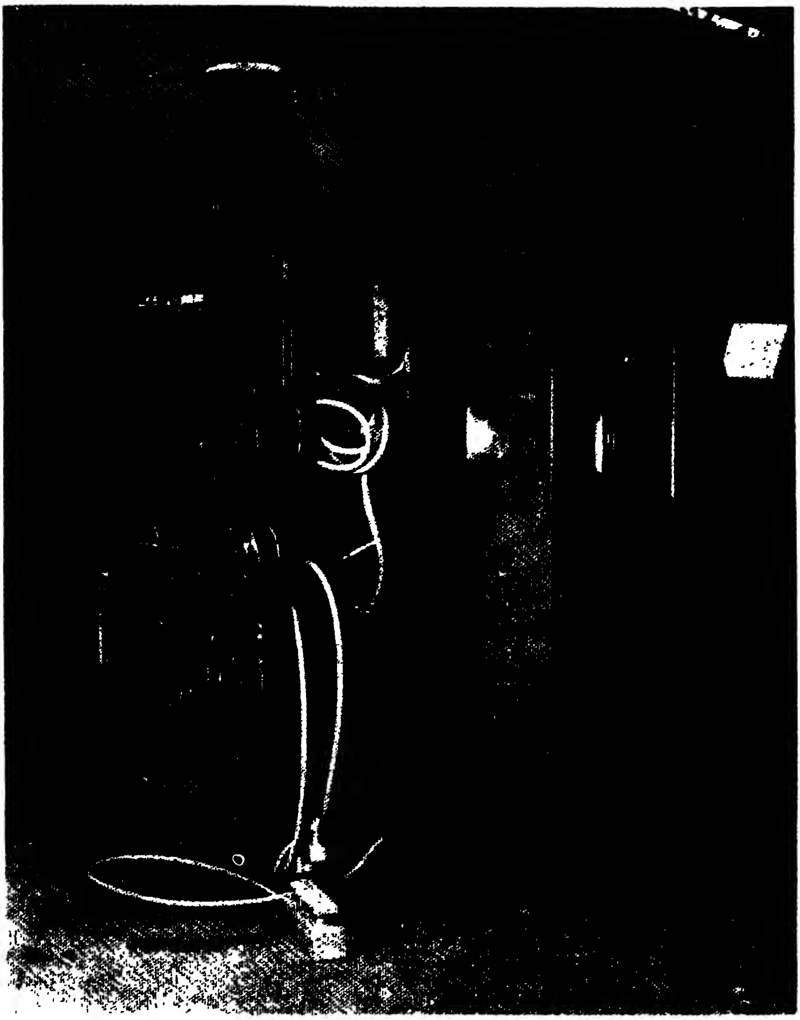
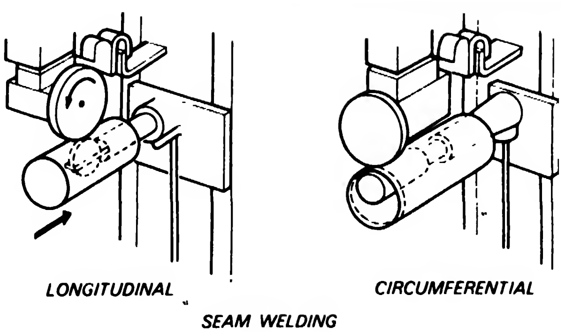


Fig. 11.10 (*c*)



it only requires guidance, and they are operated in the same way as spot welding guns.

Direct current spot welding

We have seen that when iron or steel to be welded is placed in a spot or seam welder the impedance of the secondary circuit is increased and the secondary current varies according to the mass introduced. By using d.c. this loss is obviated, the power consumed is reduced and the electrode life increased because skin effect is eliminated. This enables coated steels, stainless and other special steels in addition to aluminium alloys to be welded to high standards. The machine is similar in appearance to the a.c. machine but has silicon diodes as the rectifying elements.

Three-phase machines

Three-phase machines have been developed to give impulse of current in the secondary circuit at low frequency, with modulated wave form to give correct thermal treatment to the material being welded. These machines have greatly increased the field of application of spot welding into light alloys, stainless, and heat-resistant steels, etc. A typical sequence of operations is: squeeze, which multiplies the number of high spots between the contact faces; welding pressure, which diminishes just before the welding current flows; immediately after the passage of the current, forging or recompression pressure is applied which is above the elastic limit of the material and completes the weld. Setting of the welding current can be done by welding test pieces with increasing current until the diameter of the nugget, found by 'peeling' the joint, is $(2t + 3)$, where t is the thickness of the thinner sheet. This current is noted. It is then increased until spatter of the nugget occurs and the welding current is taken as midway between these two values, with final adjustments made on test pieces.

Nickel and nickel alloys have higher electrical resistivity and lower thermal conductivity than steel and are usually welded in thin sections as lap joints, although the crevice between the sheets may act as a stress raiser and affect the corrosion and fatigue resistance. High pressures are required for the high-nickel alloys so as to forge the solidifying nugget, and the machine should have low inertia of the moving parts so that the electrode has rapid follow-up during welding. Current may be set as in the previous section, and in some cases it is advantageous to use an initial squeeze followed by an increasing (up-sloping) current. When the nugget is just beginning to form with diffusion of the interface, the squeeze force is reduced to about one-third of its initial value and held until the current is switched off; this reduces danger of expulsion of molten metal and gives better penetration of the weld into the two sheets.

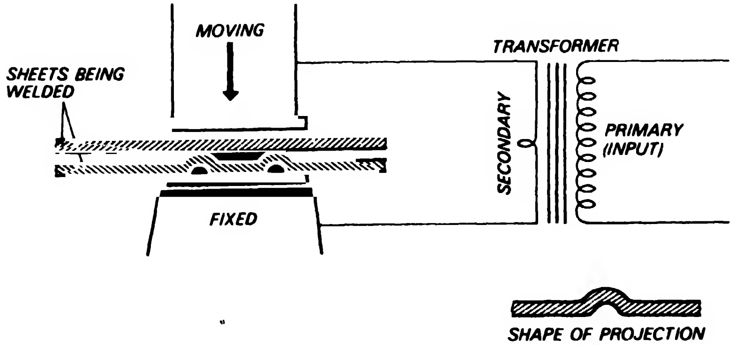
Projection welding

Protrusions are pressed on one of the sheets or strips to be welded and determine the exact location of the weld (Fig. 11.11). Upon passage of the current the projection collapses under the electrode pressure and the sheets are welded together. The machines are basically presses, the tipped electrodes of the spot welder being replaced by flat platens with T slots for the attachment of special tools, and special platens are available which allow the machine to be used as a spot welder by fitting arms and electrodes (Fig. 11.12), and automatic indexing tables can be used to give increased output. Projection welding is carried out for a variety of components such as steel radiator coupling elements, brake shoes, tin-plate tank handles and spouts, etc. The press type of machine is also used for resistance brazing in which the joining of the parts is achieved with the use of an alloy with a lower melting point than the parent metal being welded so that there is no melting involved.

Cross wire welding is a form of projection welding, the point of contact of the two wires being the point of location of the current flow. Low-carbon mild steel, brass, 18/8 stainless steel, copper-coated mild steel and galvanized steel wire can be welded but usually the bulk of the work is done with clean mild steel wire, bright galvanized, or copper coated as used for milk bottle containers, cages, cooker and refrigerator grids, etc., and generally several joints are welded simultaneously.

Modern machines are essentially spot welders in ratings of 25, 70, or 150 kVA fitted with platens upon which suitable fixtures are mounted and having a fully controlled pneumatically operated vertical head, and the electrical capacity to weld as many joints as possible simultaneously. Large programmed machines are manufactured for producing reinforcement mesh automatically.

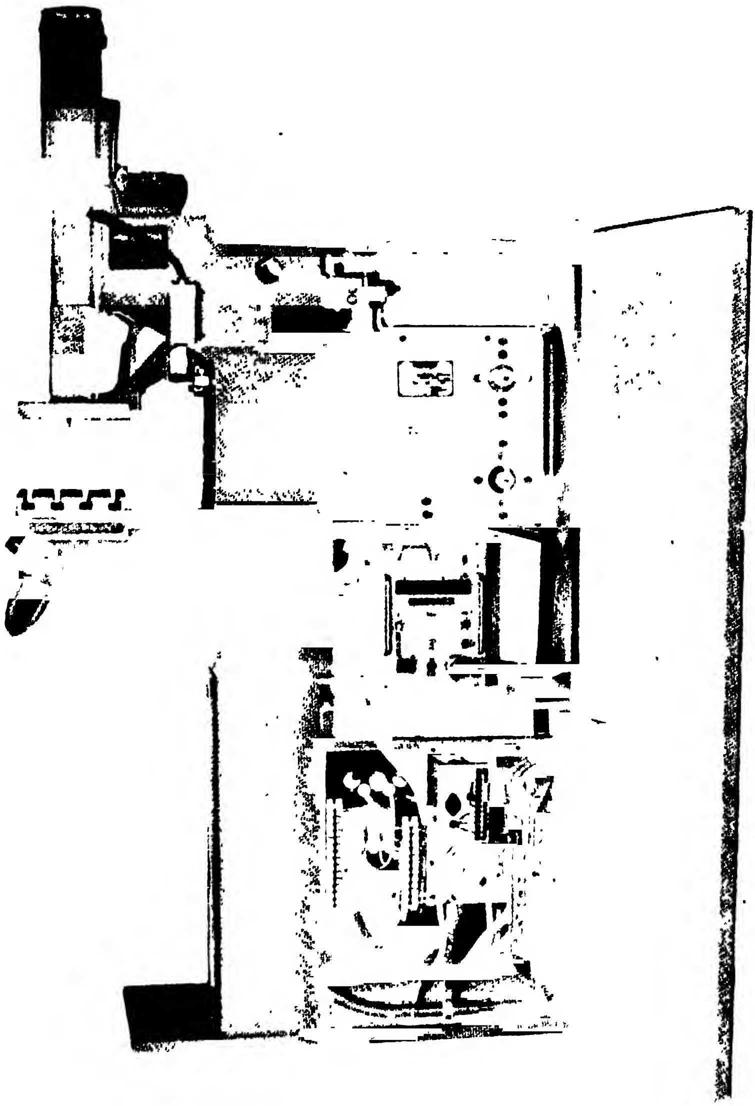
Fig. 11.11. Projection welding



Resistance butt welding

This method is similar to spot welding except that the parts to be butt welded now take the place of the electrodes. The two ends are prepared so that they butt together with good contact. They are then placed in the jaws of the machine, which presses them close together end to end (Fig. 11.13). When a given pressure has been reached, the heavy current is switched on, and the current flowing through the contact resistance

Fig. 11.12. Projection welder.



between the ends brings them to welding heat. Extra pressure is now applied and the ends are pushed into each other, the white hot metal welding together and an enlargement of section taking place. The section may be machined to size after the operation if necessary.

*Flash butt welding**

Although this is not a resistance welding process it is convenient to consider it here. Flash butt welding machines must be very robustly made and have great rigidity because considerable pressures are exerted and exact alignment of the components is of prime importance. The clamping dies of copper alloy, which carry the current to the components and hold them during butting up under high pressure, should grip over as large an area as possible to reduce distortion tendencies. The clamping pressure, which is about twice the butting pressure, is usually done pneumatically or hydraulically, and current is of the order of 7 - 10 A/mm^2 of joint area. The following are the stages in the welding cycle.

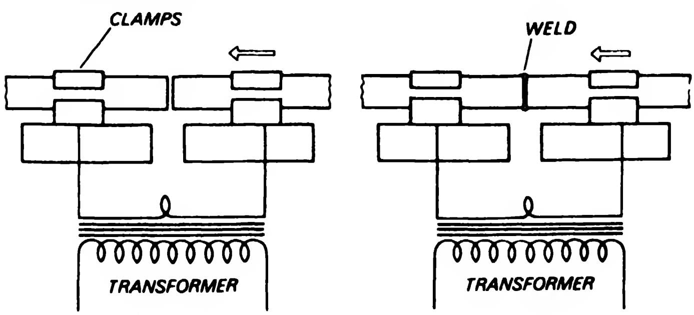
Pre-heat. The components are butted together and a current passing across the joint heats the ends to red heat.

Flash. The parts are separated and an arc is established between them until metal begins to melt, one of the components being moved to keep the arc length constant.

Upset. The parts are butted together under high pressures with the current still flowing. Impurities are forced out of the joint in the butting process and an impact ridge or flash is formed (Fig. 11.14). Post-heat treatment can be given by a variation of current and pressure after welding. For welding light alloys, pre-heating is generally dispensed with and the flashing is of short duration.

As an example of currents involved, a butt weld in 6 mm thick 18/18/3

Fig. 11.13. Resistance butt welding



* BS 499 gives this as a resistance process.

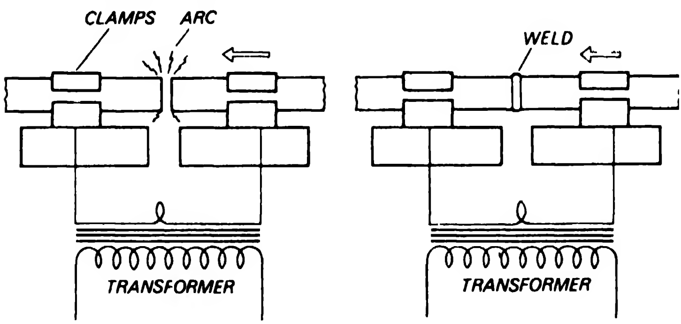
stainless steel with a cross-section of 600 mm^2 involves currents of 20 000 A with a 9 second flashing time.

Flash butt welding is used very extensively by railway systems of the world to weld rails into continuous lengths. British Rail for example weld rails approximately 18.3 m long into continuous lengths from 91 to 366 m and conductor rails are welded in the same way. Fig. 11.15 shows a modern rail welding machine. Hydraulic rams, equally spaced on each side of the rail section, apply the forging load of 200–400 kN to the rails of section approximately 7200 mm^2. The rail is clamped by two vertically acting cylinders and horizontally acting cylinders align each rail to a common datum and an anti-twist device removes axial twist. When welding long lengths of rail it is more convenient to move the machine to the exact position for welding rather than the rail and for this the machine can be rail mounted. Machines of this type can make 150–200 welds per 8-hour shift. In this case the sequence of operations is pre-flash, pre-heat, flashing and forging.

The upset is removed by a purpose-designed machine with hydraulic power-shearing action usually mounted in line with the welding machine.

The flash butt welded lengths are welded *in situ* on the track by the thermit process.

Fig. 11.14. Flash butt welding



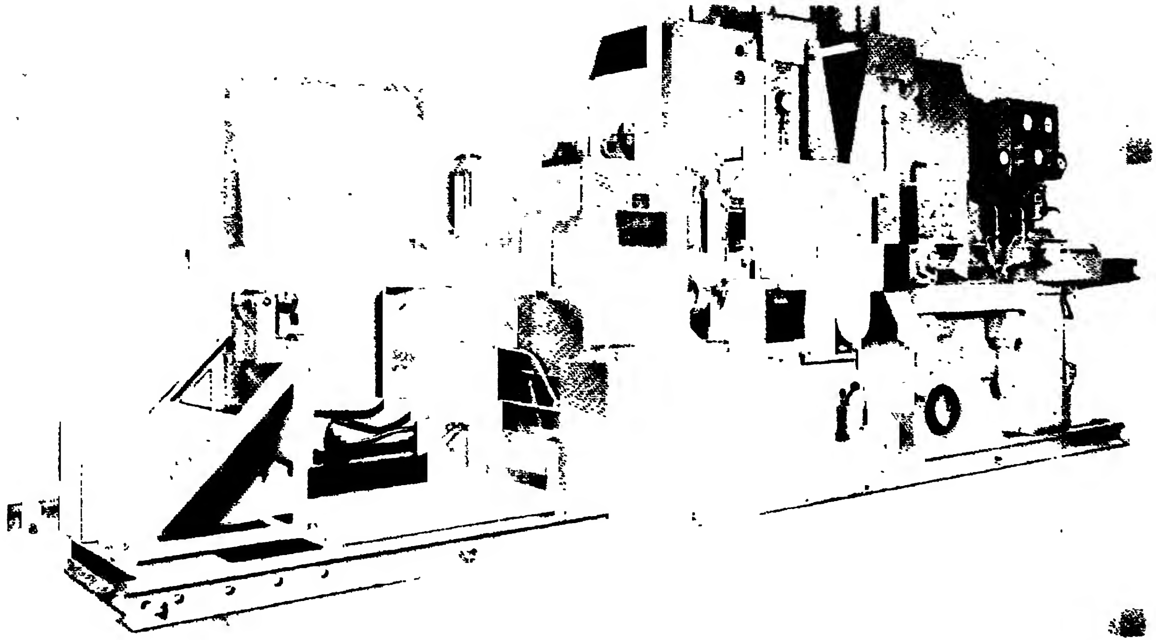


Fig. 11.15. Machine for welding rail sections. 1000 kVA. 3-phase, 440 V Welding sequence (1) Both rails securely clamped in welder. (2) Rails aligned vertically and horizontally under full clamping pressure. (3) Weld initiated by push button control. (4) Moving head moves forward on the burn-off or pre-flashing stroke used to square up the ends of the rails if necessary. On completion of this, pre-heating begins until the requisite number of pre-heats have lapsed. At this point the rails should be in a suitably plastic state to allow for straight flashing and finally forging.

12

Additional processes of welding

There has been a great increase in the number of automatic processes designed to speed up welding production. Automatic welding gives high rates of metal deposition because high currents from 400 to 2000 A can be used, compared with the limit of about 600 A with manual arc welding. Automatic arc control gives uniformly good weld quality and finish and the high heat input reduces distortion and the number of runs for a given plate thickness is reduced. Twin welding heads still further reduce welding time, and when used, for example, one on each side of a plate being fillet welded, distortion is reduced. The welding head may be:

(1) Fixed, with the work arranged to move beneath it.
(2) Mounted on a boom and column which can either be of the positioning type in which the work moves or the boom can traverse at welding speed over the fixed work.
(3) Gantry mounted so that it can traverse over the stationary work.
(4) Self propelled on a motor-driven carriage.

The processes which have been described previously in this book, namely TIG, MIG and CO_2 (gas shielded metal arc) with their modifications, are extensively used fully automatically. Heads are now available which, by changing simple components, enable one item of equipment to be used for MIG (inert gas), CO_2 and tubular wire, and submerged arc processes.

*Submerged arc welding (sub-arc)**

In this automatic process the arc is struck between bare or flux cored wire and the parent plate, the arc, electrode end and the molten pool are submerged or enveloped in an agglomerated or fused powder which

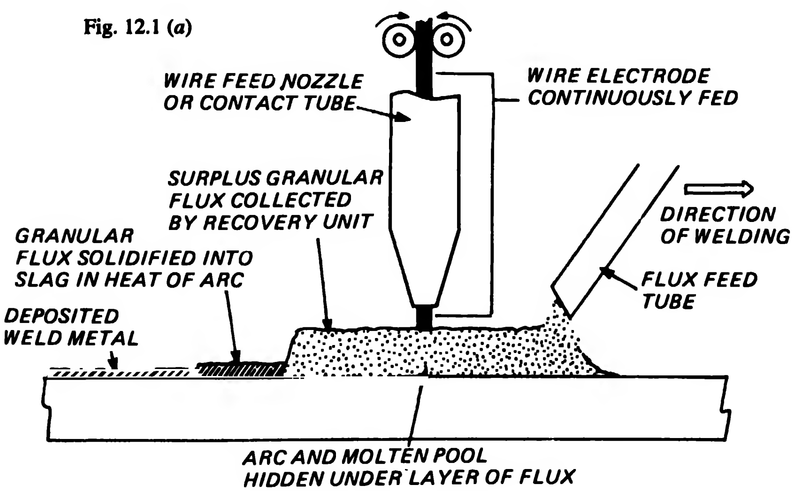
* American designation SAW (similar to British).

turns into a slag in its lower layers under the heat of the arc and protects the weld from contamination. The wire electrode is fed continuously to the arc by a feed unit of motor-driven rollers which is voltage-controlled in the same way as the wire feed in other automatic processes and ensures an arc of constant length. The flux is fed from a hopper fixed to the welding head, and a tube from the hopper spreads the flux in a continuous mound in front of the arc along the line of weld and of sufficient depth to completely submerge the arc, so that there is no spatter, the weld is shielded from the atmosphere and there are no radiation effects (UV and IR) in the vicinity. (Fig. 12.1*a* and *b*.) A latest development to increase deposition rate is to lay down a powder in front of flux feed and welding head; this is generally used with a tandem a.c./d.c. head.

Welding heads

Fully automated welding heads for this process can also be used with modification for gas shielded metal arc welding including CO_2, solid and flux cored, thus greatly increasing the usefulness of the equipment. The head can be stationary and the work moved below it, as for example in the welding of circumferential and longitudinal seams, or the head may be used with positioners or booms or incorporated into custom-built mass production welding units for fabricating such components as brake shoes, axle housings, refrigerator compressor housings, brake vacuum cylinders, etc., and hard surfacing can also be carried out. The unit can also be tractor mounted (cf. Fig. 12.2*c*) and is self-propelled, with a range of speeds of 100 mm to 2.25 m per minute, and arranged to run on guide bars or rails. Oscillating heads can be used for root runs on butt joints to maintain a

Fig. 12.1 (*a*)

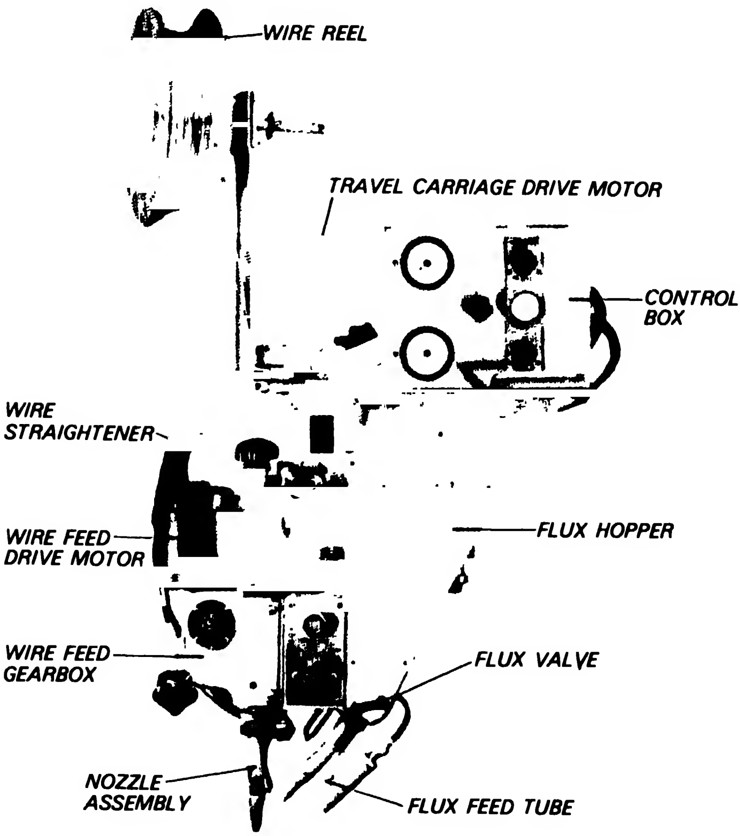


constant welding bead on the underside of the joint, and two and even three heads can be mounted together or the heads can be arranged side by side to give a wide deposit as in hard surfacing. Fillet welding can be performed by inclining two heads, one on each side of the joint, with flux feeds and recovery, the heads being mounted on a carriage which travels along a gantry over the work (Fig. 12.2). Two heads mounted in tandem and travelling either along a guide rail or directly on the workpiece are used for butt joints on thick plate, and both can operate on d.c. or the leading head can operate on d.c. and the trailing head on a.c.

Three electrode heads can be gantry mounted on a carriage, the leading electrode being d.c. operated with the trailing electrodes a.c. This method gives high deposition rates with deep penetration. Special guide units ensure in all cases that the electrode is correctly positioned relative to the joint.

The main components in the control box are: welding voltage and arc

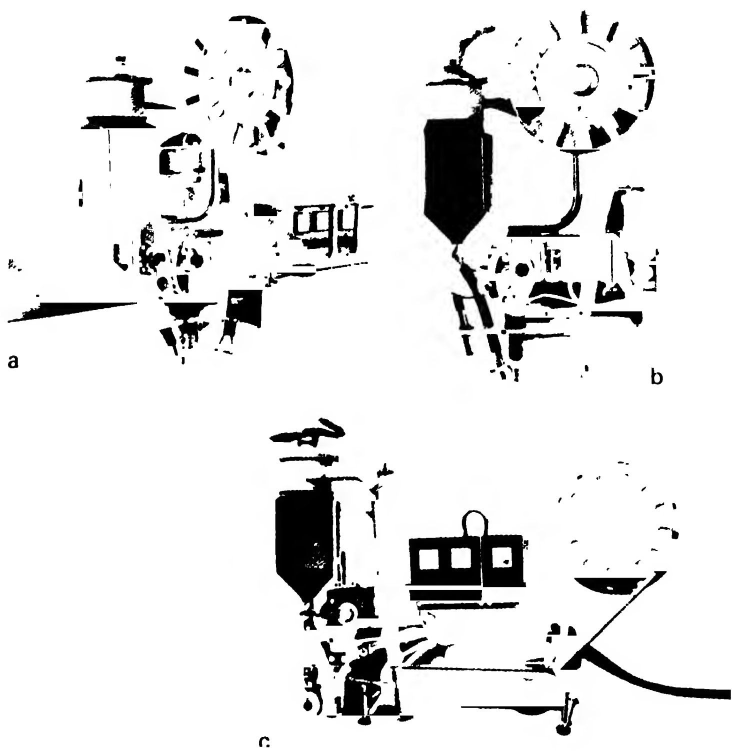
Fig. 12.1 (*b*)



current controls, and wire feed controlled by a thyristor regulator which maintains set values of arc voltage. The head is accurately positioned by slide adjusters for horizontal and vertical movement and has angular adjustment also. The wire feed motor has an integral gearbox and wire-straightening rolls give smooth wire feed. The gear ratio for the metal arc process is much higher than for submerged arc and each wire diameter usually requires its own feed rolls, which are easily interchanged. For fine wires less than 3 mm diameter a fine-wire-straightening unit can be fitted.

Current is passed to the electrode wire through a contact tube and jaws

Fig. 12.2 Various mountings for automatic welding equipment
(*a*) An automatic welding machine in which the head is mounted on a carriage which travels along a beam.
(*b*) An automatic welding head as in (*a*) designed for stationary mounting on a manipulator column or boom in order to be an integral part of a mechanized welding system
(*c*) A tractor-mounted automatic welding head as in (*a*) The machine has a single welding head and is designed for welding butt joints and for making fillet welds in the flat or horizontal vertical position



which fit the wire diameter being used, and the contact tube is used for the shielding gas when gas shielded welding is being performed and is water cooled. The coil arm holder has a brake hub with adjustable braking effect and carries 300 mm i.d. coils, and a flux hopper is connected to a flux funnel attached to the contact tube by a flexible hose.

A guide lamp which is attached to the contact tube provides a spot of light which indicates the position of the wire, thus enabling accurate positioning of the head along the joint, and a flux recovery unit collects unfused flux and returns it to the hopper.

A typical sequence of operations for a boom-mounted carriage carrying multiple welding head is: power on, carriage positioned, welding heads 1, 2, etc., down, electrode feed on, wire tips set, flux valve open, welding speed set, welding current set, welding voltage set, flux recovery on; press switch to commence welding.

Power unit

The power unit can be a motor- or engine-driven d.c. generator or transformer-rectifier with outputs in the 30–55 V range and with currents from 200 to 1600 A with the wire generally positive. In the case of multiple head units in which the leading electrode is d.c. and the trailing electrode is a.c. a transformer is also required. In general any power source designed for automatic welding is usually suitable when feeding a single head.

Wires are available in diameters of 1.6, 2.0, 2.4, 3.2, 4.0, 5.0, 6.0 mm on plastic reels or steel formers. Wrappings should be kept on the wire until ready for use and the reel should not be exposed to damp or dirty conditions.

A variety of wires are available including the following (they are usually copper coated). For mild steel types with varying manganese content, e.g. 0.5%, 1.0%, 1.5%, 2.0% manganese, a typical analysis being 0.1% C, 1.0% Mn, 0.25% Si, with S and P below 0.03%. For low alloy steels, 1,25% Cr, 0.5% Mo; 2.25% Cr, 1.0% Mo; 0.2% Mn, 0.5% Mo; and 1.5% Mn 0.5% Mo are examples, whilst for the stainless steel range there are: 20% Cr, 10% Ni for unstabilized steels; 20% Cr, 10% Ni, 0.03% C, for low-carbon 18/8 steels; 19% Cr, 12% Ni, 3% Mo for similar steels; 20% Cr, 10% Ni, nobium stabilized; 24% Cr, 13% Ni for steels of similar composition and for welding mild and low-alloy steels to stainless steel.

Many factors affect the quality of the deposited weld metal: electrode wire, slag basicity, welding variables (process), cleanliness, cooling rate, etc. For hardfacing, the alloy additions necessary to give the hard surface usually come from the welding wire and a neutral flux, and tubular wire with internal flux core is also used in conjunction with the external flux.

Hardness values as welded, using three layers on a mild steel base, are between 230 and 650 HV depending upon the wire and flux chosen.

Flux (see also pp. 61–3)

Fluxes are suitable for use with d.c. or a.c. They are graded according to their form, whether (1) fused or (2) agglomerated. Fused fluxes have solid glassy particles, low tendency to form dust, good recycling properties, good slag-flux compatibility, low combined water and little sensitivity to humid conditions. Agglomerated fluxes have irregular-sized grains with low bulk density, low weight consumption at high energy inputs with active deoxidizers and added alloying elements where required.

Fluxes are further classified as to whether they are acidic or basic, the basicity being the ratio of basic oxides to acidic oxides which they contain. In general the higher the basicity the greater the absorption of moisture and the more difficult it is to remove.*

The general types of flux include manganese silicate, calcium manganese aluminium sulphate, rutile, zirconia and bauxite, and the choice of flux affects the mechanical properties of the weld metal. Manufacturers supply full details of the chemical composition and mechanical properties of the deposited metal when using wires of varying compositions with various selected fluxes (i.e. UTS, % elongation Charpy impact value, and CTOD†) figures at various temperatures).

Fluxes that have absorbed moisture should be dried in accordance with the makers' instructions, as the presence of moisture will affect the mechanical properties of the deposited metal. The flux, whether fused or agglomerated, should be chosen to give the weld as near as possible the same characteristics as the parent plate. Wire composition and chosen flux must be compatible. Tensile and yield strength, together with impact values of the welded joint must all be considered.

The strength of carbon–manganese steels depends upon the carbon, silicon and manganese content. Of these, the manganese content can most easily be varied by additions to the flux to obtain the various levels of strength. In general, the manganese content of the weld metal should be equal to or exceed that of the parent plate. Too much manganese will result in brittleness. The impact value is governed by the basicity of the flux; an increase of basicity results in a decrease of arc stability, a reduction in weld appearance and more difficult slag removal. In general

* Basicity (BI) = $\dfrac{CaO + CaF_2 + MgO + K_2O + Na_2O + \frac{1}{2}(MnO + FeO)}{SiO_2 + \frac{1}{2}(Al_2O_3 + TiO_2 + ZrO_2)}$ The basicity may vary from 0.7 to 3.1 (see also pp.63–4).

† Crack tip opening displacement, pp. 296–301.

the flux of highest basicity consistent with stable arc, good weld appearance and easy slag removal should be chosen.

Electrode wires, wound on reels, are available, together with compatible fluxes for carbon manganese steels, low-alloy steels and stainless steels. See table, p. 523, for filler wire and fluxes.

Joint preparation

Joint edges should be carefully prepared and free from scale, paint, rust and oil, etc., and butt seams should fit tightly together. If the fit-up has gaps greater than 0.8 mm these should be sealed with a fast manual weld.

When welding curved circumferential seams there is a tendency for the molten metal and slag, which is very fluid, to run off the seam. This can be avoided or reduced by having the welding point 15–65 mm before top dead centre in the opposite direction to the rotation of the work and in some cases the speed of welding and current can be reduced. Preparation of joints is dependent upon the service to which the joint is to be put and the following preparations are given as examples only (Fig. 12.3).

Backing

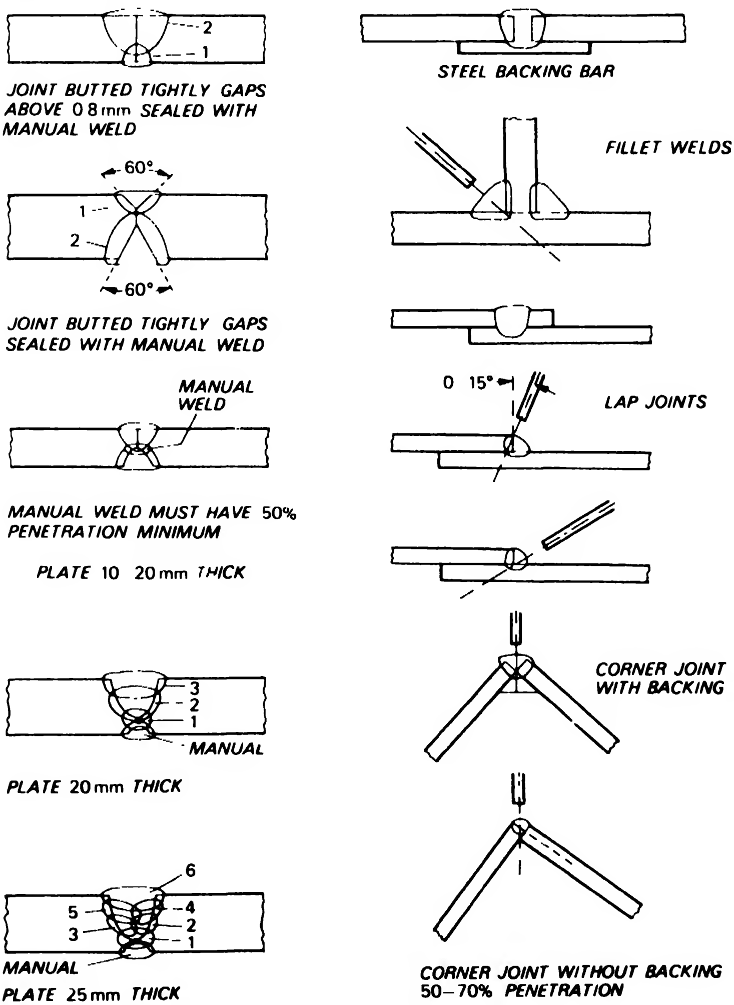
As the cost of back-chipping and making a sealing run has escalated it becomes more and more necessary to be able to weld plates and cylinders of large size with a run on one side only. This may be the case, for example, if the fit-up of the sections is poor and a weld in the root of the section may not be able to bridge a wide root gap successfully. In these cases a backing can be used so that the weld is performed from one side only and with which a good profile of underbead is obtained even when fit-up and alignment are not good. The following are examples of differing types of backing strips available.

Ceramic tile backing strip. This is shown in section in Fig. 12.4*a* and is suitable for slag-forming processes such as submerged arc, or flux cored and MMA can be used for vertical and horizontal- vertical butts. A recess in the tile allows the slag to form below the underbead and is stripped off and discarded with the aluminium foil which holds it in position as the weld progresses.

Fibreglass tape backing strip is a closely woven flexible material of about four to six layers and fibreglass tape which gives good support to the underbead or root run of the weld and is usually used in conjunction with a copper or aluminium backing bar. It is non-hygroscopic and has low fume level. Sizes are from 30 mm wide heavy single layer, 35 mm wide four layer and 65 mm wide six layer.

Fibreglass tape, sintered sand backing plate. This is typical for submerged arc single or twin wire as in large structures, e.g. deck plates in shipyards, etc. The backing is of sintered sand (silica) about 600 mm long, 50 mm wide and 10 mm thick reinforced with steel wires. It has a fibreglass tape fitted to the upper surface to support the root of the weld and has adhesive outer edges to allow for attachment to the joint, which should be dry and which should have a 40–50° included angle preparation and a root gap of about 4 mm. The backing is slightly flexible to allow for errors of alignment and has 45° bevelled ends. Overlapping tape prevents burn-through at the

Fig. 12.3. Types of butt welds



backing junction. An aluminium section can be used as undersupport if required (Fig. 12.4*b*).

Electroslag welding (Fig. 12.5)

Developed in Russia, this process is used for butt welding steel sections usually above 60 mm in thickness although plates down to 10 mm thick can be welded. The sections to be welded are fixed in the vertical position and part of the joint line, where welding is to commence, is enclosed with water-cooled copper plates or dams which serve to position the molten weld metal and slag. The dams are pressed tightly against each side of the joint to prevent leakage. There may be from one to three electrode wires depending upon the thickness of the section and they are fed continuously from spools. The self-adjusting arc is struck on to a run-off plate beneath a coating of powder flux which is converted into a liquid in about half a minute. The current is then transferred, not as an arc but through the liquid slag, which gives the same order of voltage drop as would the arc. During welding some slag is lost in forming a skin between the molten metal and the copper dams, and a flow of powder, carefully metered to avoid disturbing the welding conditions, is fed in to make good wastage. The vertical traverse may be obtained by mounting the welding

Fig 12.4. (*a*) Ceramic tile backing strip

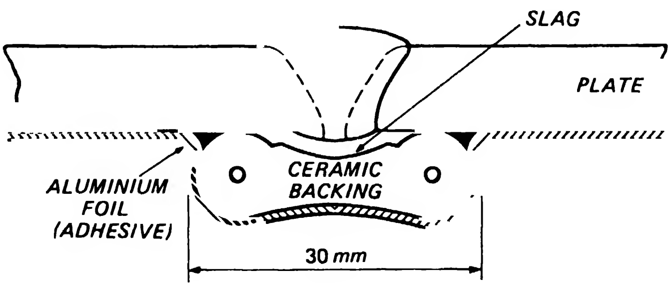
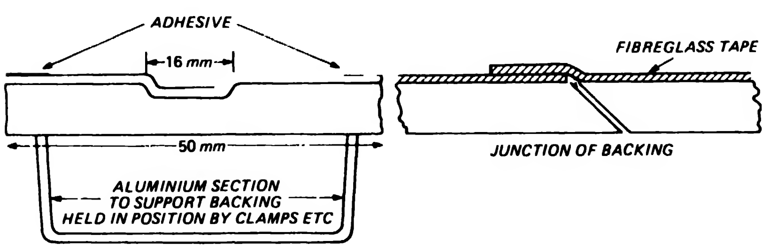


Fig.12.4 (*b*)



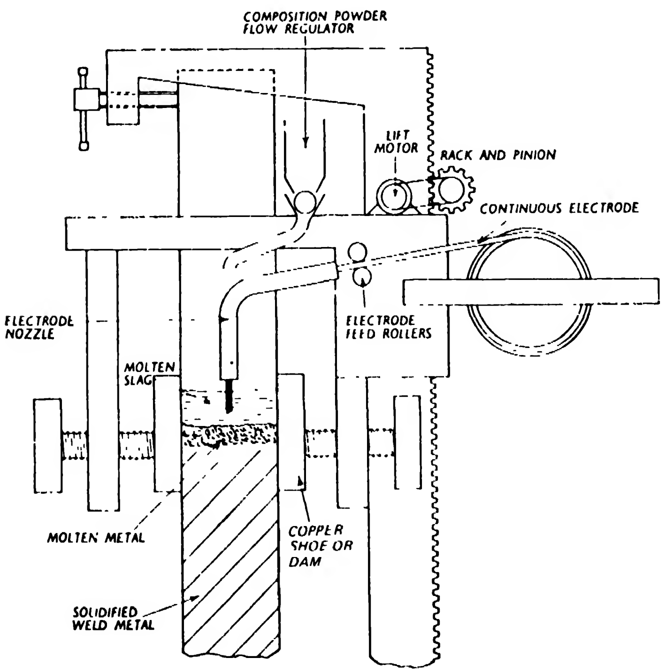
head on a carriage which is motor-driven and travels up a rack on a vertical column in alignment with the joint to be welded. The rate of travel is controlled so that the electrode nozzle and copper dams are in the correct position with regard to the molten pool, and since the electrode is at right angles to the pool, variations in fit-up are not troublesome. For thick sections the electrodes are given a weaving motion across the metal.

The welds produced are free from slag inclusions, porosity and cracks, and the process is rapid, preparation is reduced, and there is no deslagging. Composite wires containing deoxidizers and alloying elements can be used when required. A variation of the process uses a CO_2 shield instead of the flux powder, the CO_2 being introduced through pipes in the copper dams just above the molten metal level.

Electroslag welding with consumable guides or nozzles

Consumable guide welding is a development of the electroslag process for welding straight joints in thick plate in the vertical or near vertical position, in a range of 15–40 mm thick plate and with joints up to 2 m long. The set-up gap between plates is 25-30 mm, but when welding

Fig 12.5. Principle of electroslag or vertical submerged melt welding



thicknesses less than 20 mm the joints can be reduced to 18–24 mm, the gap ensuring that the guide tube does not touch the plate edges. Water-cooled copper shoes act as dams and position the molten metal and also give it the required weld profile. As with electroslag welding the current passing through the molten slag generates enough heat to melt the electrode end, guide and edges of the joint, ensuring a good fusion weld. If a plain uncoated guide tube is used, flux is added to cover the electrode and guide end before welding commences. To start the process the arc is struck on the work. It continues burning under the slag with no visible arc or spatter. The slag should be viewed through dark glasses as in gas cutting because of its brightness when molten.

An a.c. or d.c. power source in the range 300–750 A is suitable, such as is used for automatic and MMA processes. Striking voltage is of the order of 70–80 V, with arc voltages of 30–50 V, higher with a.c. than d.c.

The advantages claimed for the process are: relatively simpler, cheaper, and more adaptable than other similar types, faster welding than MMA of thick plate, cheaper joint preparation, even heat input into the joint thus reducing distortion problems, no spatter losses, freedom from weld metal defects and low consumption of flux. Fig 12.6 illustrates the layout of the machine.

Mechanized MIG welding with robots (robotics)

Fully automatic welding using the gas shielded metal arc or submerged arc processes in conjunction with columns and booms, positioners, rotators and other equipment such as jigs is extensively used for the making of welds either straight, circumferential or circular. The use of robots in the car industry for spot welding the body shell, spray painting and general assembly is well known and it has resulted in increased speed of production and less overall cost with reduced monotony and fatigue for the operator.

Now consider the robot adapted to the fabrication of large numbers of similar components with welds in all positions performed by the gas shielded metal arc process.

The word robot comes from the Czech word *robota* which, in translation, means any class of work that involves monotony, repetition or drudgery. When operating the robot the welder becomes the supervisor for whom the robot works, performing this monotonous work at speed, with accuracy and not getting tired or needing breaks.

To serve as an example we can consider one particular modern robot illustrated in Fig 12.7.

This has six degrees of freedom, (one being optional) based on the

human hand, wrist and forearm and the following gives the approximate movement values:

> rotational 340°, radial arm 550 mm max., vertical arm 850 mm max., wrist bending 90°, wrist turning 180°.

The accuracy of these movements is 0.1–0.2 mm at 500 mm distance and it should be noticed that the robot can be equipped with heads for selection, grinding, polishing and spot welding, if required.

Evidently there must be large production runs of components with repetitive welding to be performed for the cost of the station, consisting of positioners, control cabinets, robot with gas shielded metal arc welding,

Fig. 12.6. (*a*) Consumable guide layout showing water-cooled dams

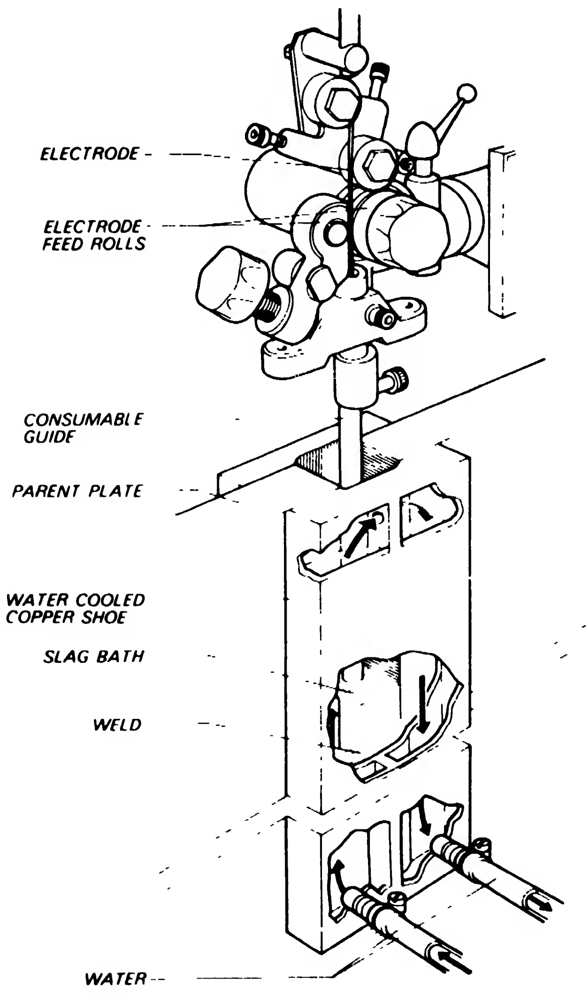


Fig. 12.6. (*b*) Completed weld

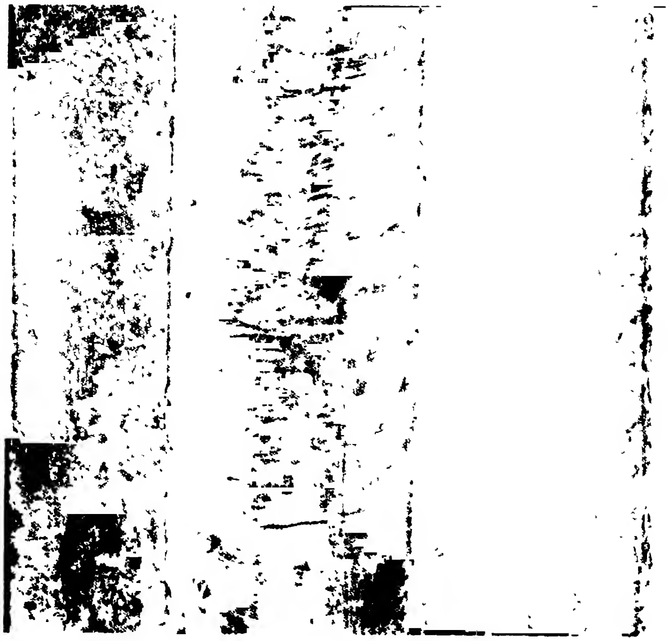
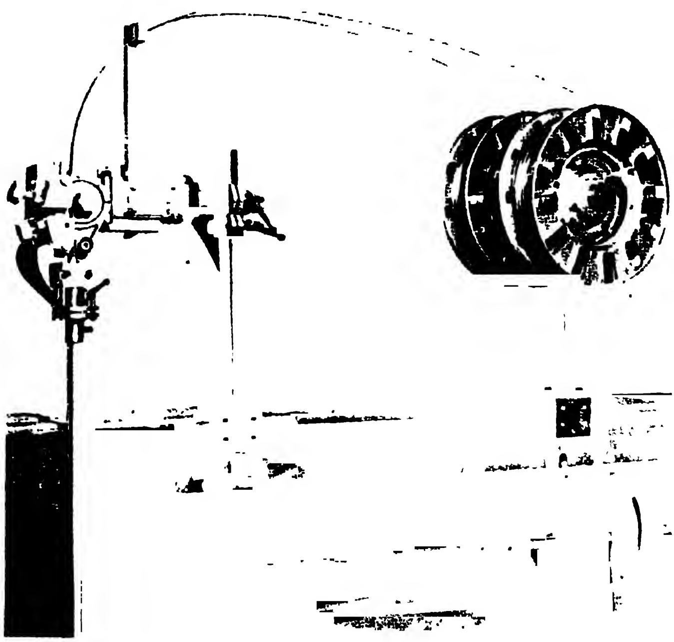


Fig. 12.6. (*c*) The consumable guide welding process using, in this case, twin wire/tube system The dams have been removed to show the position of the guide tubes.



Key

1 Control panel, by which operator determines when robot should start welding the next work piece

2 Handling unit Different types are available On this one fixtures for the component are mounted on tilting turntables

3 Handling unit on same foundation as robot giving stability and accuracy

4 Screen

5. Welding robot with rapid, accurate movements

6a Constant voltage power source for welding head Wire feed unit can be positioned separately

6b Wire reel

6c Programming unit

6d Wire feed

7 Control cabinet, controlling movements and where removable programming unit is located Program is stored on tape cassette

head and power and control unit, to be justified Once the decision has been taken for the outlay to be justified the advantages that accrue are great.

The production station, which varies according to the size of the work pieces, can consist, for example, of two positioners, on which the work is jig held. These positioners (**Fig. 12.8**) and the data required in the welding operations are controlled by a microcomputer and are servo-steered.

The robot head has a gas shielded metal arc welding gun adapted to fit the head, the power source is of the thyristor-controlled constant voltage type and the wire is fed from a unit which controls speed of feed and compensates for variations of mains voltage and friction of the feed rollers.

To program the robot, the programming unit is taken from the control cabinet and the robot run through the complete welding sequence for the part to be fabricated. The welding gun is moved from point to point and each section is fed with the speed required and the welding parameters (current and voltage, etc.), and the accelerated movement from one welding point to the next is also programmed and mistakes are easily corrected. The computer memory has say 500 position capacity with additional instructions with a tape recorder increasing the memory. The storage of the program is on a digital tape cassette so that the switch from one program to another can be made without starting from scratch. As is usual pre- and post-flow of the shielding gases and crater filling are all part of the program. (*Note*. The TIG method of welding may also be performed by robots See **Chapter 10**.)

Fig. 12.8. Computer control, servo-powered positioner Dual axes, fast and accurate handling, Self-braking worm gears

Pressure welding

This is the joining together of metals in the plastic condition (not fusion) by the application of heat and pressure as typified by the blacksmith's weld. In general the process is confined to butt welding. The parts (tubes are a typical example) are placed on a jig which can apply pressure to force the parts together.

The faces to be welded are heated by oxy-acetylene flames, and when the temperature is high enough for easy plastic flow to take place, heating ceases and the tubes are pushed together causing an upset at the welded face. The welding temperature is about 1200 C for steel. It is considered that atoms diffuse across the interfaces and recrystallization takes place, the grains growing from one side to the other of the welded faces since they are in close contact due to the applied pressure. Any oxide is completely broken up at a temperature well below that of fusion welding but due to the heating time concerned, grain growth is often considerable. Steel, some alloy steels, copper, brass, and silver can be welded by this process.

Cold pressure welding

Cold pressure welding is a method of joining sections of metal together by the application of pressure alone using no heat or flux. Pressure

Fig. 12.9

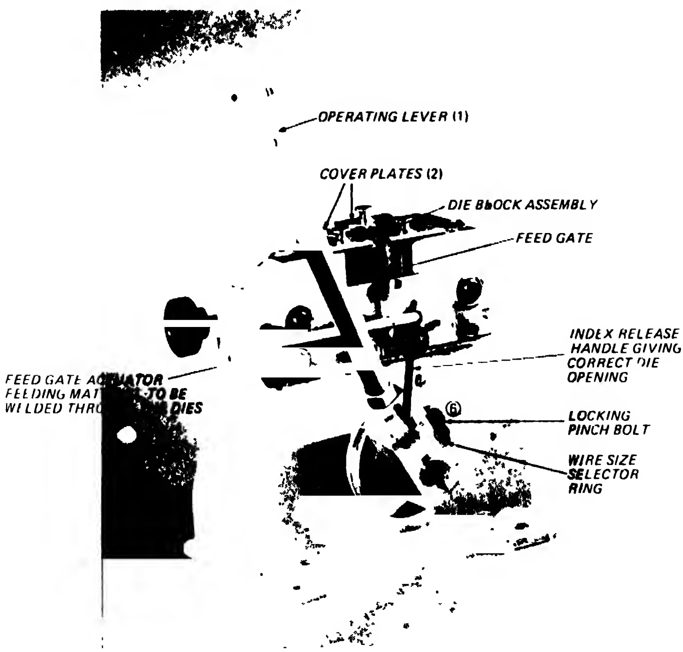


Fig. 12.10. (*a*) Cold pressure weld, aluminium to copper (wire 9.5 mm diameter) × 25

Fig. 12.10. (*b*) Cold pressure weld, copper to copper (wire 8 mm diameter) × 25

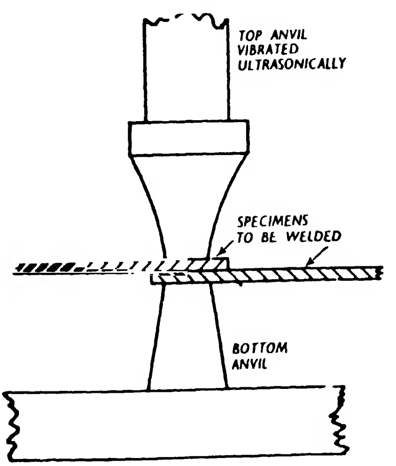
is applied to the points to be welded at temperatures below the recrystallization temperature of the metals involved. This applied pressure brings the atoms on the interface to be welded into such close contact that they diffuse across the interface and a cold pressure weld is made.

It is a method for relatively ductile metals such as aluminium, copper cupro-nickel, gold, silver, platinum, lead, tin and lead- tin alloys, etc., and it is particularly suited to welds in circular wire section. In the type described of the multiple upset type, the surfaces to be welded are placed in contact and held in position by gripping dies and are fed together in small increments by a lever (Fig. 12.9). Each lever movement giving interface pressure displaces the original surfaces by plastic flow and after about four to six upsets, the last movement completes the weld and the flash is easily removed. In the machine illustrated, copper wire 1.1 3.5 mm diameter max. or aluminium wire to 4.75 max. can be butt welded. Fig. 12.10*a* and *b* illustrates the micrographs of welds made in copper to copper and copper to aluminium wire.

Ultrasonic welding

Ultrasonic vibrations of several megacycles per second (the limit of audibility is 20 000 30 000 Hz) are applied to the region of the faces to be welded. These vibrations help to break up the grease and oxide film and heat the interface region. Deformation then occurs with the result that welding is possible with very greatly reduced pressure compared with an ordinary pressure weld. Very thin section and dissimilar metals can be welded and because of the reduced pressure there is reduced deformation (Fig. 12.11).

Fig. 12.11 Ultrasonic welding



Friction welding

The principle of operation of this process is the changing of mechanical energy into heat energy. One component is gripped and rotated about its axis while the other component to be welded to it is gripped and does not rotate but can be moved axially to make contact with the rotating component. When contact is made between rotating and non-rotating parts heat is developed at the contact faces due to friction and the applied pressure ensures that the temperature rises to that required for welding. Rotation is then stopped and forging pressure applied, causing more extrusion at the joint area, forcing out surface oxides and impurities in the form of a flash (Fig. 12.12). The heat is concentrated and localized at the interface, grain structure is refined by hot work and there is little diffusion across the interface so that welding of dissimilar metals is possible.

In general at least one component must be circular in shape, the ideal situation being equal diameter tubes, and equal heating must take place over the whole contact area. If there is an angular relationship between the final parts the process is not yet suitable.

The parameters involved are: (1) the power required, (2) the peripheral speed of the rotating component, (3) the pressure applied and (4) the time of duration of the operation. By adjusting (1), (2) and (3), the time can be reduced to the lowest possible value consistent with a good weld.

Power required. When the interfaces are first brought into contact, maximum power is required, breaking up the surface film. The power required then falls and remains nearly constant while the joint is raised to welding temperature. The power required for a given machine can be chosen so that the peak power falls within the overload capacity of the driving motor. It is the contact areas which determine the capacity of a machine. The rotational speed can be as low as 1 metre per second peripheral and the pressure depends upon the materials being welded, for example for mild steel it can be of the order of 50 N/mm^2 for the first part of the cycle followed by 140 N/mm^2 for the forging operation. Non-ferrous metals require a somewhat greater difference between the two operations. The faster the rotation of the component and the greater the pressure, the shorter the weld cycle, but some materials suffer from hot cracking if the cycle is too short and the time is increased with lower pressure to increase the width of the HAZ. At the present time most steels can be welded including stainless, but excluding free cutting. Non-ferrous metals are also weldable and aluminium (99.7% Al) can be welded to steel.

Fig. 12.12 (*a*) Friction welding

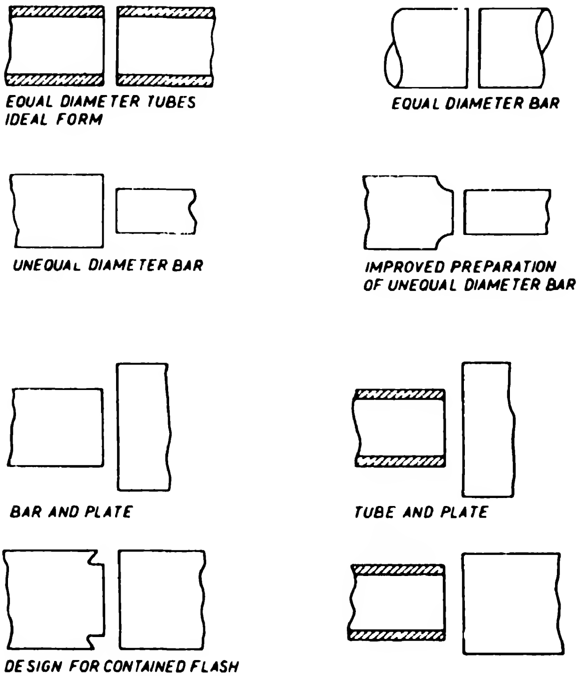


Fig **12.12** (*b*) Suitable forms of friction welding

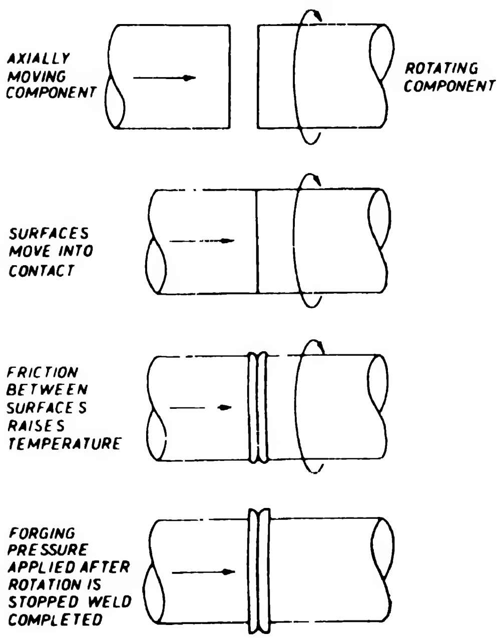
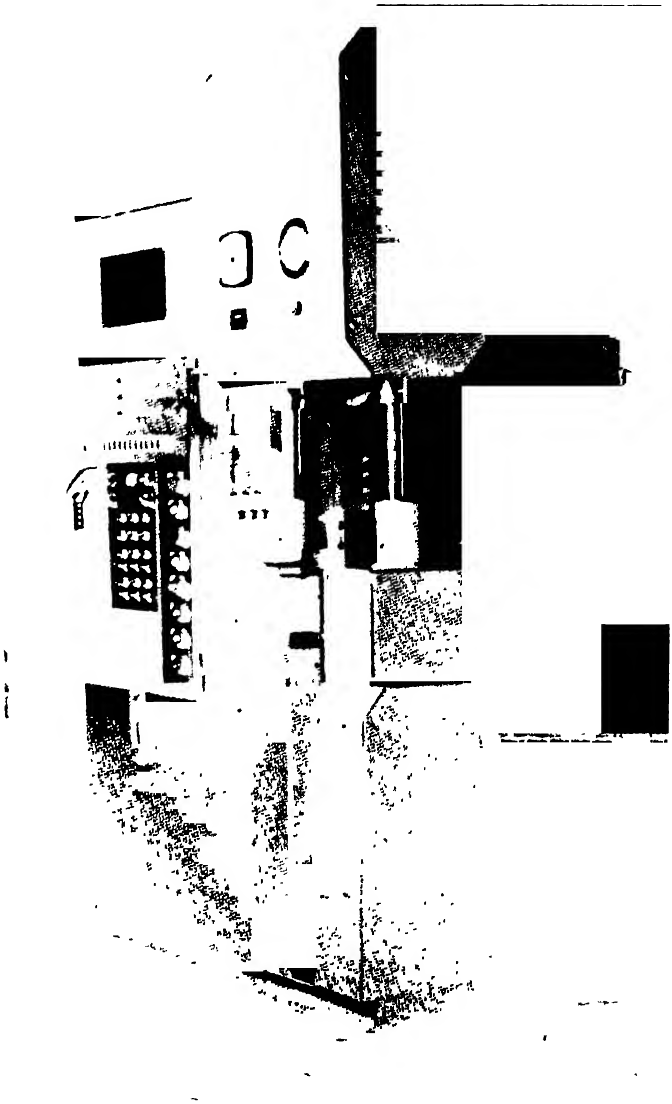


Fig. 12.13 Friction welder



There are various control systems: (1) Time control, in which after a given set time period after contact of the faces, rotation is stopped and forge pressure is applied. There is no control of length with this method. (2) Burn-off to length: parts contact and heating and forging take place within a given pre-determined length through which the axially moving component moves. (3) Burn-off control: a pre-determined shortening of the component is measured off by the control system when minimum pressures are reached. Weld quality and amount of extrusion are thus controlled, but not the length. (4) Forging to length· the axially moving work holder moves up to a stop during the forging operation irrespective of the state of the weld and generally in this case extrusion tends to be excessive.

The extrusion of flash can be removed by a subsequent operation or, for example for tubes of equal diameter, a shearing unit can be built into the machine operating immediately after forging and while the component is hot, thus requiring much less power. Fig. 12.12(*a*) illustrates a joint designed to contain the flash.

In the process known as inertia welding the rotating component is held in a fixture attached to a flywheel which is accelerated to a given speed and then uncoupled from its drive. The parts are brought together under high thrust and the advantage claimed is that there is no possibility of the driving unit stalling before the flywheel energy is dissipated.

Friction welding machines resemble machine tools in appearance, as illustrated in Fig. 12.13.

Electron beam welding

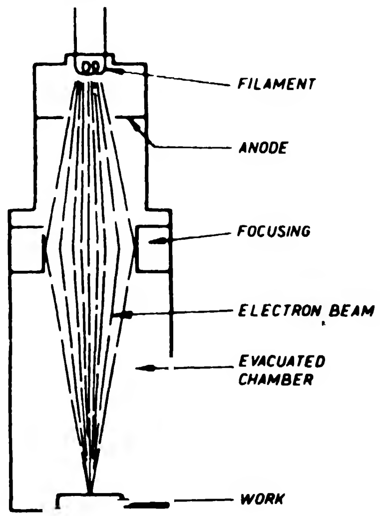
If a filament of tungsten or tantalum is heated to high temperature in a vacuum either directly by means of an electric current or indirectly by means of an adjacent heater, a great number of electrons are given off from the filament, which slowly evaporates. This emission has been mentioned previously in the study of the tungsten arc welding process. The greater the filament current the higher the temperature and the greater the electron emission, and if a metal disc with a central hole is placed near the filament and charged to a high positive potential relative to the filament, so that the filament is the cathode and the disc the anode, the emitted electrons are attracted to the disc and because of their kinetic energy pass through the hole as a divergent beam. This can then be focused electrostatically, or magnetically, by means of coils situated adjacent to the beam and through which a current is passed. The beam is now convergent and can be spot focused. The basic arrangement, an electron 'gun', is similar to that used

for television tubes and electron microscopes **(Fig. 12.14).**

If the beam is focused on to a metal surface the beam can have sufficient energy to raise the temperature to melting point, the heating effect depending upon the kinetic energy of the electrons. The kinetic energy of an electron is $\frac{1}{2}mV^2$, where m is the mass of an electron (9.1×10^{-28} g) and V its velocity. The electron mass is small, but increasing the emission from the filament by raising the filament current increases the number of electrons and hence the mass effect. Because the kinetic energy varies directly as the square of the velocity, accelerating the electrons up to velocities comparable with the velocity of light by using anode voltages (up to 200 kV) greatly increases the beam energy. The smaller the spot into which the beam is focused the greater the energy density but final spot size is often decided by working conditions, by aberration in the focusing system, etc., so that spot size may be of the order of 0.25–2.5 mm.

When the beam strikes a metal surface X-rays are generated, so that adequate precautions must be taken for screening personnel from the rays by using lead or other metal screens or making the metal walls of the gun chamber sufficiently thick. If the beam emerges into the atmosphere the energy is reduced by collision of the electrons with atmospheric molecules and focus is impaired. Because of this it has been the practice to perform many welding operations in a vacuum, either in the gun chamber in which case each time the component is loaded the chamber must be evacuated to high vacuum conditions, thus increasing the time and cost of the operation, or in a separate steel component chamber fixed to the gun chamber. This can be made of a size to suit the component being welded and is evacuated

Fig. 12.14. Electron beam welding



to a relatively low vacuum after each loading. In either case welds suffer no contamination because of vacuum conditions. Viewing of the spot for set-up, focusing and welding is done by various optical arrangements

Welding in non-vacuum conditions requires much greater power than for the preceding method because of the effects of the atmosphere on the beam and the greater distance from gun to work, and a shielding gas may be required around the weld area. Research work is proceeding in this field involving guns of higher power consumption Difficulties may also be encountered in focusing the beam if there is a variation in the gun-to-work distance, as on a weld on a component of irregular shape.

Welds made with this process on thicker sections are narrow with deep penetration with minimum thermal disturbance and at present welds are performed in titanium, niobium, tungsten, tantalum, beryllium, nickel alloys (e.g. nimonic), inconel, aluminium alloys and magnesium, mostly in the aero and space research industries. The advantages of the process are that being performed in a vacuum there is no atmospheric contamination and the electrons do not affect the weld properties, accurate control over welding conditions is possible by control of electron emission and beam focus, and there is low thermal disturbance in areas adjacent to the weld (Fig. 12.15). Because of the vacuum conditions it is possible to weld the more reactive metals successfully On the other hand the equipment is very costly, production of vacuum conditions is necessary in many cases and there must be protection against radiation hazards

Laser beam welding*

Radio waves, visible light, ultra-violet and infra-red radiations are electro-magnetic radiations which have two component fields, one electric and the other magnetic, vibrating at right angles to each other and to the direction of propagation of the beam. If either one of these components is suppressed the resulting radiations are said to be polarized and the direction in which the resultant electric or magnetic forces act is the plane of polarization. Light from a source such as a tungsten filament electric light consists of several frequencies involving various shades of colour. These waves are not in phase and are of various amplitudes and planes of polarization, and the light is said to be non-coherent. Light of a single wave-length or frequency is termed monochromatic. The wave-length of light is measured in metres or micro-metres, termed microns (μm), visible light being in the range 0.4–0.7 μm. The frequency is related to the wave-length by the expression $V = n\lambda$, where n is the frequency in Hz, λ the wave-length in metres and V the velocity of electro-magnetic radiation,

* The velocity of light is 3×10^{10} cm/s (~ 186000 mps)

3×10^8 m/s, so that the frequency range of visible light is in the range 430–750×10^{12} Hz.

Atoms of matter can absorb and give out energy and the energy of any atomic system is thereby raised or lowered about a mean or 'ground' level. When an atom or molecule is at an energy level higher than that of the ground state (or level) it is said to be excited, and in this condition two similar atoms can combine to form a molecule called a 'dimer'. The combination is for an extremely short time, and only when in the excited state. Energy can only be absorbed by atoms in definite small amounts (quanta) termed photons, and the relationship between the energy level and the frequency of the photon is $E = h\nu$, where E is the energy level, h is Planck's constant and ν the photon frequency, so that the energy level depends upon the frequency of the photon. An atom can return to a lower energy level by emitting a photon and this takes place in an exceedingly short space of time from when the photon was absorbed, so that if a photon of the correct frequency strikes an atom at a higher energy level, the photon which is released is the same in phase and direction as the incident photon.

The principle of the laser (Light Amplification by Stimulated Emission of Radiation) is the use of this stimulated energy to produce a beam of

Fig. 12.15. Electron beam welding machine with indexing table, tooled for welding distributor shafts to plates at a production rate of 450 per hour. The gun is fitted with optical viewing system. Power 7.5 kW at 60 kV, 125 mA. Vacuum sealing is achieved by seals fitted in the tooling support plate and at the bottom of the work chamber. As the six individual tooling stations reach the welding station they are elevated to the weld position and then rotated by an electronically controlled d.c. motor.

coherent light, that is one which is monochromatic, and the radiation has the same plane of polarization and is in phase. Lasers operate with wavelengths in the visible and infra-red region of the spectrum. When the beam is focused into a small spot and there is sufficient energy, welding, cutting and piercing operations can be performed on metals.

The ruby laser has a cylindrical rod of ruby crystal (Al_2O_3) in which there is a trace of chromium as an impurity. An electronic flash gun, usually containing neon, is used to provide the radiation for stimulation of the atoms. This type of gun can emit intense flashes of light of one or two milliseconds duration and the gun is placed so that the radiations impinge on the crystal. The chromium atoms are stimulated to higher energy levels, returning to lower levels with the emission of photons. The stimulation continues until an 'inversion' point is reached when there are more chromium atoms at the higher levels than at the lower levels, and photons impinging on atoms at the higher energy level cause them to emit photons. The effect builds up until large numbers of photons are travelling along the axis of the crystal, being reflected by the ends of the crystal back along the axis, until they reach an intensity when a coherent pulse of light, the laser beam (of wave-length about 0.63 μm), emerges from the semi-transparent rod end. The emergent pulses may have high energy for a short time period, in which case vaporization may occur when the beam falls on a metal surface, or the beam may have lower energy for a longer time period, in which case melting may occur, while a beam of intermediate power and duration may produce intermediate conditions of melting and vaporization, so that control of the time and energy of the beam and focusing of the spot exercise control over the working conditions.

Developments of the ruby laser include the use of calcium tungstate and glass as the 'host' material with chromium, neodymium, etc., as impurities, a particular example being yttrium aluminium–garnet with neodymium (YAG), used for operations on small components.

The CO_2 laser uses carbon dioxide for its main gas, with a little helium or nitrogen. The tube may be some metres long, the average length of the beam (10.6 μm) being longer than that of the solid state laser and other continuous wave or pulsed (the power increasing with the length of the tube). To increase the power without increasing the length of the unit, folded-beam lasers have many shorter tubes set parallel to each other; the beam passes down each tube and is reflected from specially ground polished copper mirrors set at an angle of 45° to the beam at the end of each tube. As with other gas lasers, electrical stimulation is by means of an HF discharge from a tube (similar to a flourescent tube).

A solid state laser (ruby, Nd–YAG), with its operational wave-length of 1.06 μm in the infra-red wave band, uses the heating effect of the beam. Gas lasers

use argon fluoride, krypton fluoride and xenon fluoride (and chlorides), giving a pulsed beam of 25–50 W at the ultra-violet end of the spectrum with little or no heat. On starting the tube, electrical stimulation from a radio frequency (r.f.) generator is connected to each end of the tube. The helium atoms, or those of other seeding gases, are stimulated and their energy level raised above ground level. These atoms transfer their energy to the other gas in the tube, until inversion occurs and a coherent beam is emitted. This is known as collision excitation and gas lasers are used for visual effects of various colours.

The excimer laser is of the helium neon type and stimulation of the gas is to an energy level such that two atoms combine to form a 'dimer'. Energy is obtained from an HF electrical discharge through the tube. When the laser beam strikes a surface it dissociates the bond between the molecules and removes the surface by chemical action. It is used at present for micro-machining metallic and non-metallic surfaces, in rubbers, polymers, papers, glass etc., and for surface hardening, marking and cutting thin foils.

2 kW CO_2 lasers can be used to weld up to 3 mm thick material and are an alternative to the electron beam for thin gauge material. The width of the weld may be increased at speeds below 12 mm/s due to interaction between the beam and an ionized plasma which occurs near the work. At speeds of 20 mm/s and over, laser and electron beam welds are practically indistinguishable from one another.

Stud welding

This is a rapid, reliable and economical method of fixing studs and fasteners of a variety of shapes and diameters to parent plate. The studs may be of circular or rectangular cross-section, plain or threaded internally or externally and vary from heavy support pins to clips used in component assembly.

There are two main methods of stud welding: (1) arc (drawn arc), (2) capacitor discharge, and the process selected for a given operation depends upon the size, shape and material of the stud and the composition and thickness of the parent plate, the arc method generally being used for heavier studs and plate, and capacitor discharge for lighter gauge work.

Arc (drawn arc) process

This is used in both engineering and construction work and the equipment consists of a d.c. power source, controller and a hand-operated or bench-mounted tool or gun.

A typical unit consists of a forced-draught-cooled power source with a 380/440 V, 3-phase, 50 Hz transformer, the secondary of which is

connected to a full-wave, bridge-connected silicon rectifier (p. 202) with tappings giving ranges of 120–180 A, 170–320 A, and 265–1500 A approximately (equipment is also available up to 1800 A), at about 65 V. The two lower ranges can also be used for MMA welding and two or more units can be connected in parallel if required, the loading being shared automatically.

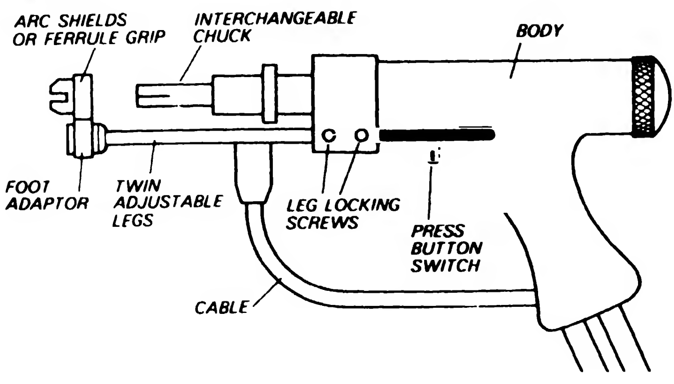
The power controller contains a main current contactor and timer relays and a pilot arc device, energized from the d.c. source. The solid-state timer has a multi-position switch or switches for the selection of operating time and current for the diameter of stud in use. Work is usually connected to the positive pole with the stud negative except for aluminium, when the polarity is reversed.

The hand gun (Fig. 12.16) has the operating solenoid and return spring within the gun body, which also carries the operating switch and adjustable legs to accommodate varying lengths of studs, an interchangeable chuck for varying stud diameters and a foot adaptor to maintain concentricity between the stud and ferrule or arc shield, this latter being held by ferrule grips. Studs are fluxed on the contact end, which is slightly pointed (Fig. 12.17), and are supplied with ferrules.

To operate the equipment, the welding current and time for the diameter of stud in use are selected, the stud is loaded into the appropriate chuck, the legs adjusted for length and the stud positioned on the plate. A centre punch can be used for locating the stud point and the plate should be free of contamination.

Sequence of operations. The gun switch is pressed, a low current flows between pointed stud end and workpiece and immediately the stud is raised, drawing an arc and ionizing the gap. The main current contactor now closes and full welding current flows in an arc, creating a molten state

Fig. 12.16

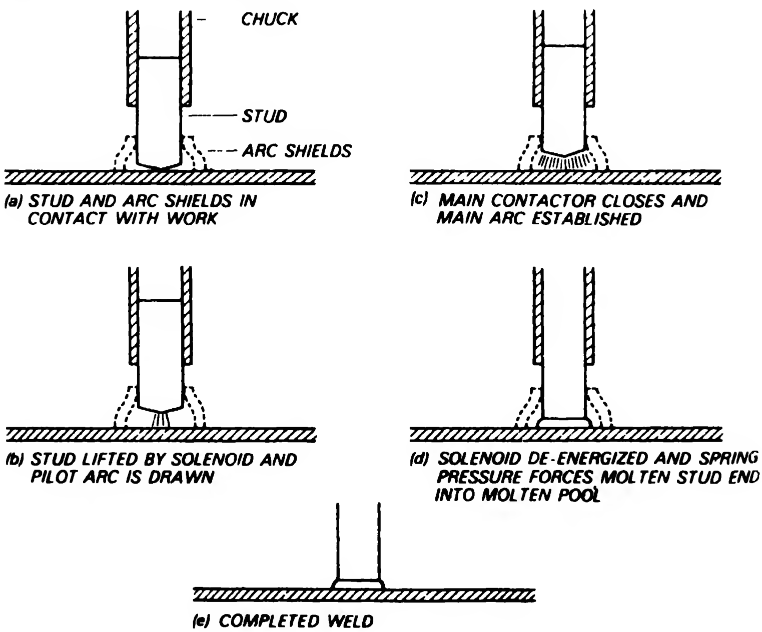


in plate and stud end. The solenoid is de-energized and the stud is pushed under controlled spring pressure into the molten pool in the plate. Finally the main current contactor opens, the current is switched off, and the operation cycle is complete, having taken only a few hundredths of a second (Fig. 12.17).

This method, which is usually employed, whereby the welding current is kept flowing until the return cycle is completed, is termed 'hot plunge'. If the current is cut off just before the stud enters the molten pool it is termed 'cold plunge'. The metal displaced during the movement of the stud into the plate is moulded into fillet form by the ceramic ferrule or arc shield held against the workpiece by the foot. This also protects the operator, retains heat and helps to reduce oxidation.

Studs from 3.3 mm to 20 mm and above in diameter can be used on parent plate thicker than 1.6 mm, and the types include split, U shaped, J bent anchors, etc. in circular and rectangular cross-section for the engineering and construction industries, and can be in mild steel (low carbon), austenitic stainless steel, aluminium and aluminium alloys (3–4% Mg). The rate of welding varies with the type of work, jigging, location, etc., but can be of the order of 8 per minute for the larger diameters and 20 per minute for smaller diameters.

Fig. 12.17. Arc stud welding, cycle of operations.



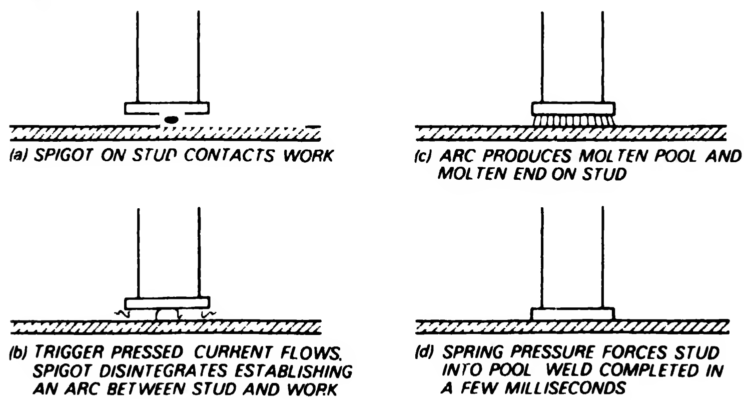
Capacitor discharge stud welding

In this process a small projection on the end of the stud makes contact with the workpiece and the energy from a bank of charged capacitors (see pp. 179–80) is discharged across the contact, melting the stud projection, ionizing the zone and producing a molten end on the stud and a shallow molten pool in the parent plate. At this time the stud is pushed into the workpiece under controlled spring pressure, completing the weld (Fig. 12.18).

If C is the capacitance of the capacitor, Q the charge and V the potential difference across the capacitor, then $C = Q/V$ or *capacitance = charge/potential*. The energy of a charged capacitor is $\frac{1}{2}QV$, and since $Q = CV$, the energy is $\frac{1}{2}CV^2$, so that the energy available when a capacitor is discharged is dependent upon: (1) the capacitance the greater the capacitance the greater the energy; (2) the square of the potential difference (voltage) across the capacitance. The greater this voltage, the greater the energy. Thus the energy required for a given welding operation is obtained by selection of the voltage across the capacitor, i.e. that to which it is charged, and the total capacitance in the circuit.

In the contact method of capacitor discharge welding the small projection on the stud end is placed in contact with the workpiece as explained above. In the hold-off method, useful for thin gauge plate to avoid reverse marking, a holding coil in the hand gun is energized when the welding power is selected in the 'hold-off' position on the capacitor switch. When the stud is pushed into the gun-chuck both stud and chuck move into the hold-off position giving a pre-set clearance between the projection on the stud end and the workpiece. When the gun switch is pressed the hold-off

Fig. 12.18. Capacitor discharge stud welding, sequence of operations



coil is de-energized and spring pressure pushes the stud into contact with the workpiece, the discharge takes place and the weld is made.

This process minimizes the depth of penetration into the parent metal surface and is used for welding smaller diameter ferrous and non-ferrous studs and fasteners to light gauge material down to 0.45 mm thickness in low-carbon and austenitic stainless steel, and 0.7 mm in aluminium and its alloys and brass, the studs being from 2.8 to 6.5 mm diameter. Studs are usually supplied with a standard flange on the end to be welded (Fig.12.18) but this can be reduced to stud diameter if required and centre punch marks should not be used for location. The studs can be welded on to the reverse side of finished or coated sheets with little or no marking on the finished side. The studs are not fluxed and no arc shield or ferrule is required.

Typical equipment with a weld time cycle of 3–7 milliseconds consists of a control unit and a hand- or bench-mounted tool or gun.

The control unit houses the banks of capacitors of 100 000–200 000 μF capacitance depending upon the size of the unit, the capacitance required for a given operation being selected by a switch on the front panel. The control circuits comprise a charging stage embodying a mains transformer and a bridge-connected full-wave silicon rectifier and the solid-state circuits for charging the capacitors to the voltage predetermined by the voltage sensing module. Interlocking prevents the energy being discharged by operating the gun switch until the capacitors have reached the power pre-set by voltage and capacitance controls.

The printed circuit voltage sensing module controls the voltage to which the capacitors are charged and switches them out of circuit when they are charged to the selected voltage, and is controlled by a voltage dial on the panel. A panel switch is also provided to discharge the capacitors if required.

Solid-state switching controls the discharge of the capacitors between stud and work, so there are no moving contactors. The gun, similar in appearance to the arc stud welding gun, contains the adjustable spring pressure unit which enables variation to be made in the speed of return of the stud into the workpiece, and a chuck for holding the stud. Legs are provided for positioning or there can be a nosecap gas shroud for use when welding aluminium or its alloys using an argon gas shield. The weld cannot be performed until legs or shroud are firmly in contact with the workpiece.

Welding rates attainable are 12 per minute at 6.35 mm diameter to 28 per minute at 3.2 mm diameter in mild steel. Similar rates apply to stainless steel and brass but are lower for aluminium because of the necessity of argon purging. Partial scorch marks may indicate cold laps (insufficient

energy) with the possibility of the stud seating too high on the work. The weld should show even scorch marks all round the stud, indicating a sound weld. Excessive spatter indicates the use of too much energy.

Automatic single- and multiple-head machines, pneumatically operated and with gravity feed for the fasteners, are currently available.

Explosive welding

This process is very successfully applied to the welding of tubes to tube plates in heat exchangers, feedwater heaters, boiler tubes to clad tube plates, etc.; and also for welding plugs into leaking tubes to seal the leaks.

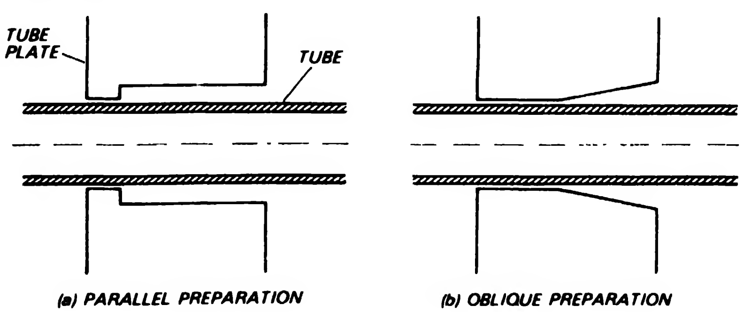
The welds made are sound and allow higher operating pressures and temperatures than with fusion welding, and the tubes may be of steel, stainless steel or copper; aluminium brass and bronze tubes in naval brass tube plates are also successfully welded.

The tube and tube plate may be parallel to each other (parallel geometry) with a small distance between them and the tube plate can be counterbored as in Fig. 12.19*a*. The explosive (e.g. trimonite) must have a low detonation velocity, below the velocity of sound in the material, and there is no limit to the joint area so that the method can be used for cladding surfaces. For the tube plate welds several charges can be fired simultaneously, the explosive being in cartridge form.

In the oblique geometry method now considered (YIMpact patent) the two surfaces are inclined at an angle to each other, Fig. 12.19*b*, the tube plate being machined or swaged as shown. As distance between tube and plate continuously increases because of the obliquity, there is a limit to the surface area which can be welded because the distance between tube and plate becomes too great.

The detonation value of the explosive can be above the velocity of sound

Fig. 12.19



in the material and the explosive (e.g. PETN) can be of pre-fabricated shape and is relatively cheap. The charge is fired electrically from a fuse head on the inner end of the charge and initiates the explosion, the detonation front then passing progressively through the charge.

The size of the charge depends upon the following variables: surface finish, angle of inclination of tube and plate, yield strength and melting point of the materials, the tube thickness and diameter; and the upper limit of the explosive is dependent upon the size of ligament of the tube plate between tubes, this usually being kept to a minimum in the interest of efficient heat exchange.

The tube plate is tapered towards the outer surface otherwise there would be a bulge in the tube on the inner side after welding and the tube would be difficult to remove. The charge must be fired from the inner end so that the weld will progress from contact point of tube and plate and thus the detonator wires must pass backwards along the charge to the outer end of the tube, the charge being withn a polythene insert (**Fig. 12.20*a***).

Upon initiation of the explosion, tube and tube plate collide at the inner end of the taper and, due to the release of energy, proceed along it, and ideally the jet of molten metal formed at the collision point is ejected at the tube mouth. In effect the welded surfaces assume a sinusoidal wave form, some of the molten metal, which is rather porous and brittle, being entrapped in the troughs and crests of the wave. This entrapment can be reduced to a minimum by having a good surface finish (e.g. of the order of 0.003 mm) and the angle between tube and tube plate from 10° to 15°. At the lower angle the waves are pronounced and of shorter wavelength while at the higher angle the wavelength is longer and the waves more undulating so that 15° is the usual angle (**Fig. 12.20*b* and *c***).

Surface oxide and impurities between the surfaces increase the charge required compared with a smooth surface and the positioning of the charge is important. If it is too far in, the energy at the mouth of the tube is not sufficient to produce a weld in this region, while if the charge is not far enough in the tube, welding is not commenced until some distance along the taper. To position the charge correctly and quickly a polythene insert has been developed to contain the charge and is positioned by a brass plug.

At present tubes of any thickness and of diameters 16–57 mm are weldable, with plate thickness greater than 32 mm and 9.5 mm plate ligaments.

The plug for explosive plugging of leaking tubes is of tubular form, the end of which is swaged to give the necessary taper, the polythene insert protruding beyond the open end of the plug to allow for extraction in case of misfire, thus increasing the safety factor (**Fig. 12.21**).

Fig. 12.20

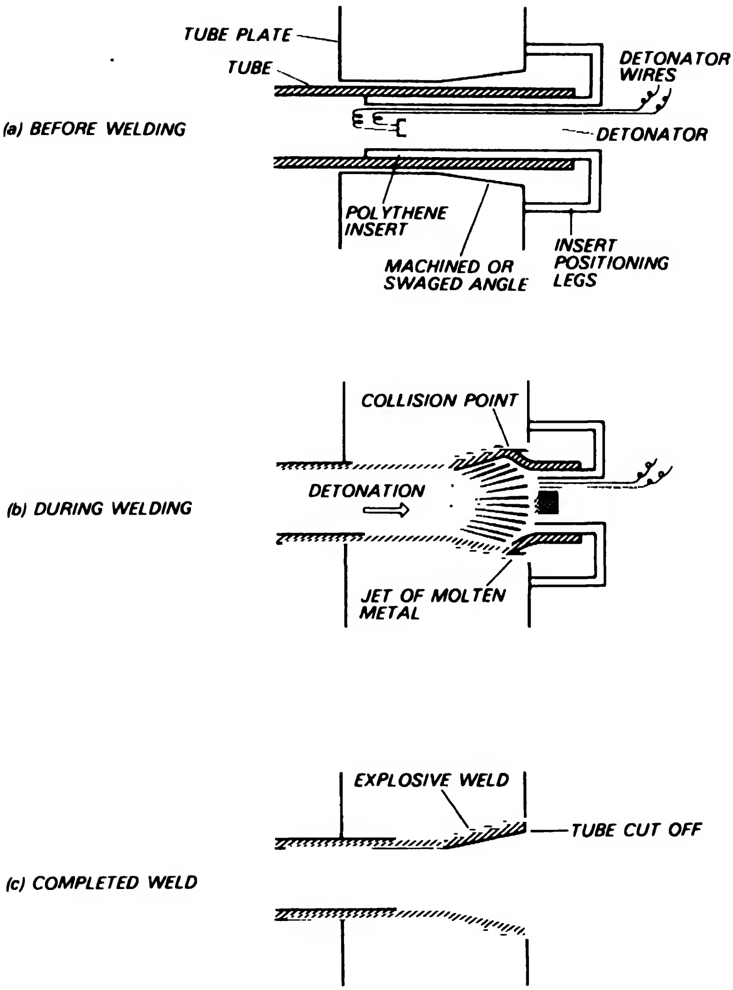
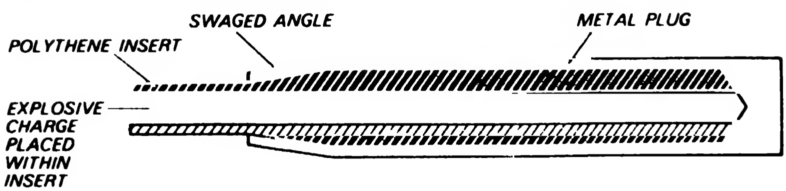


Fig. 12.21. A swaged explosive plug



Since all the configuration is confined to the plug, the tube plate hole is cleaned by grinding, the plug with explosive charge is inserted and the detonator wires connected. The plugs are available in diameters with 1.5 mm increments.

This method has proved very satisfactory in reducing the time and cost in repair work of this nature.

Personnel can be trained by the manufacturers or trained personnel are available under contract.

Gravity welding

This is a method for economically welding long fillets in the flat position using gravity to feed the electrode in and to traverse it along the plate. The equipment is usually used in pairs, welding two fillets at a time, one on each side of a plate, giving symmetrical welds and reducing stress and distortion. The electrode holder is mounted on a ball-bearing carriage and slides smoothly down a guide bar, the angle of which to the weld can be adjusted to give faster or slower traverse and thus vary the length of deposit of the electrode and the leg length of the weld.

The special copper alloy electrode socket is changed for varying electrode diameters and screws into the electrode holder, the electrode being pushed into a slightly larger hole in the socket and held there by the weight of the carriage. Turning the electrode holder varies the angle of electrode inclination. The base upon which the guide and support bar is mounted has two small ball bearings fitted so that it is easy to move along the base plate when resetting. If the horizontal plate is wider than about 280 mm a counterweight can be used with the base, otherwise the base can be attached to the vertical plate by means of two magnets or a jig can be used in place of the base to which the segment is fixed. A flexible cable connects the electrode holder to a disconnector switch carried on the support arm. This enables the current to be switched on and off so that electrodes can be changed without danger of shock. A simple mechanism at the bottom of the guide bar switches the arc off when the carriage reaches the bottom of its travel (Fig. 12.22).

At the present time electrodes up to 700 mm long are available in diameters of 3.5, 4.0, 4.5, 5.0 and 5.5 mm using currents of 220–315 A with rutile, rutile-basic and acid coatings suitable for various grades of steel.

Gravity welding is usually used for fillets with leg lengths of 5–8 mm, the lengths being varied by altering the length of deposit per electrode. An a.c. power source is used for each unit with an OCV of 60 and arc volts about 40 V with currents up to 300 A. Sources are available for supplying up to 6

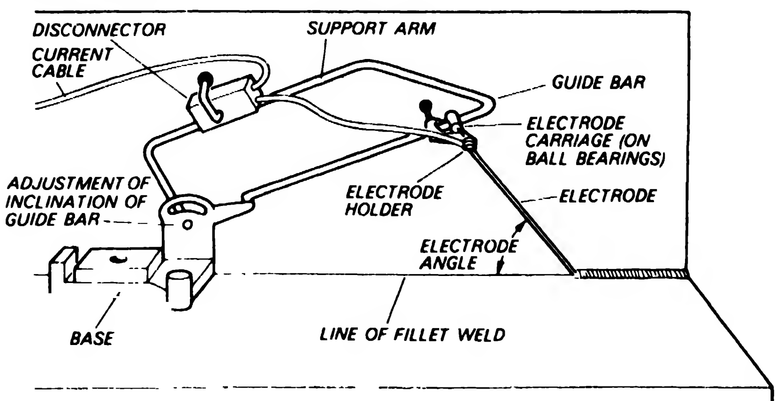
units (three pairs), manageable by one welding operator and so arranged that when the current setting for one unit is chosen, the remaining units are supplied at this value. In general gravity welding is particularly suitable for welding, for example, long parallel stiffeners on large unit panels, enabling one operator to carry out three or four times the deposit length as when welding manually.

Thermit welding

Thermit (or alumino-thermic) is the name given to a mixture of finely divided iron oxide and powdered aluminium. If this mixture is placed in a fireclay crucible and ignited by means of a special powder, the action, once started, continues throughout the mass of the mixture, giving out great heat. The aluminium is a strong reducing agent, and combines with the oxygen from the iron oxide, the iron oxide being reduced to iron.

The intense heat that results, because of the chemical action, not only melts the iron, but raises it to a temperature of about 3000 C. The aluminium oxide floats to the top of the molten metal as a slag. The crucible is then tapped and the superheated metal runs around the parts to be welded, which are contained in a mould. The high temperature of the iron results in excellent fusion taking place with the parts to be welded. Additions may be made to the mixture in the form of good steel scrap, or a small percentage of manganese or other alloying elements, thereby producing a good quality thermit steel. The thermit mixture may consist of about 5 parts of aluminium to 8 parts of iron oxide, and the weight of thermit used will depend on the size of the parts to be welded. The ignition

Fig. 12.22. Gravity welding



powder usually consists of powdered magnesium or a mixture of aluminium and barium peroxide.

Preparation

The ends which are to be welded are thoroughly cleaned of scale and rust and prepared so that there is a gap between them for the molten metal to penetrate well into the joint. Wax is then moulded into this gap, and also moulded into a collar round the fracture. This is important, as it gives the necessary reinforcement to the weld section. The moulding box is now placed around the joint and a mould of fireclay and sand made, a riser, pouring gate and pre-heating gate being included. The ends to be welded are now heated through the pre-heating gate by means of a flame and the wax is first melted from between the ends of the joint. The heating is continued until the ends to be welded are at red heat This prevents the thermit steel being chilled, as it would be if it came into contact with cold metal. The pre-heating gate is now sealed off with sand and the thermit process started by igniting the powder. The thermit reaction takes up to about 1 minute, depending upon the size of the charge and the additions that have been made in the form of steel scrap and alloying elements etc. When the action is completed the steel is poured from the crucible through the pouring gate, and it flows around the red-hot ends to be welded, excellent fusion resulting. The riser allows extra metal to be drawn by the welded section when contraction occurs on cooling, that is it acts as a reservoir. The weld should be left in the mould as long as possible (up to 12 hours), since this anneals the steel and improves the weld.

Thermit steel is pure and contains few inclusions. It has a tensile strength of about 460 N mm^{-2} The process is especially useful in welding together parts of large section, such as locomotive frames, ships' stern posts and rudders, etc. It is also being used in place of flash butt welding for the welding together of rail sections into long lengths.

At the present time British Rail practice is to weld 18 m long rails into lengths of 91 to 366 m at various depots by flash butt welding. These lengths are then welded into continuous very long lengths *in situ* by means of the thermit process and conductor rails are welded in the same way. Normal running rails have a cross-sectional area of 7184 mm^2 and two techniques are employed, one requiring a 7 minute pre-heat before pouring the molten thermit steel into the moulds and the other requiring only $1\frac{1}{4}$ minutes preheat, the latter being the technique usually employed. Excess metal can be removed by pneumatic hammer and hot chisel or by portable trimming machine.

Underwater welding

The three main methods of underwater welding at present are (1) wet, (2) localized dry chamber, (3) dry habitat (surroundings).

Wet welding

Wet welding is performed by the diver-welder normally using surface diving or saturation diving techniques using the MMA process with electrodes specially coated with insulating varnishes to keep them dry.

Current is supplied by a generator of some 400 A capacity at 60 100 OCV, directly to the welding torch head. Interchangeable collets of 4 mm and 4.8 mm ($\frac{5}{32}''$ and $\frac{3}{16}''$), hold electrodes of these diameters and are tightened by the twist-grip control, which is also used to eject the stub when electrodes are changed. Watertight glands and washers prevent seepage of water into the body of the torch, which is tough rubber covered thus reducing the danger of electric shock.

Arc stability is less than that in air due to the large volumes of gas and steam which are evolved, making vision difficult and as a result touch welding is generally used. The presence of water in the immediate vicinity of the weld except at the molten pool under the arc stream results in the very rapid quenching of the weld metal, which produces a hard, narrow heat affected zone and can give rise to severe hydrogen cracking. At present this method is used for non-critical welds, critical welding being carried out under dry conditions.

Localized dry chamber (hyperbaric)

These chambers, in which welding is performed at pressure above one atmosphere, are generally made of steel and are constructed with antichambers around the section to be welded. Water is then displaced from the chamber by gas pressure. The gas in the chamber used by the diver-welder is typically a mixture of helium and oxygen (heliox). This mixture eliminates the harmful effect of nitrogen, the helium being the carrier for the oxygen – a partial pressure of oxygen above 2 bar can be poisonous. The oxygen content is adjusted until the diver-welder does not use a breathing mask, but at the moment of welding he puts on a breathing–welding mask which has a gas supply separate from that of the chamber and umbilicals connected to the mask to enable the breathing gases to be exhausted outside the chamber.

TIG, MMA and flux cored methods of welding are used down to a depth of 300 m of water but TIG, using high purity argon as the shielding gas, is

the slowest method as it is a low deposition rate process. It can be used for root runs and hot passes, but MMA or the flux cored method is used for filling and capping. Stringer bead techniques may be used to impart toughness, and temper beads to minimize HAZ hardness. Generally the high-strength, basic-coated steel electrodes which may contain iron powder are used. They are pre-heated in a drying oven immediately before use and pre-heat of about 100 C can be applied locally to the joint.

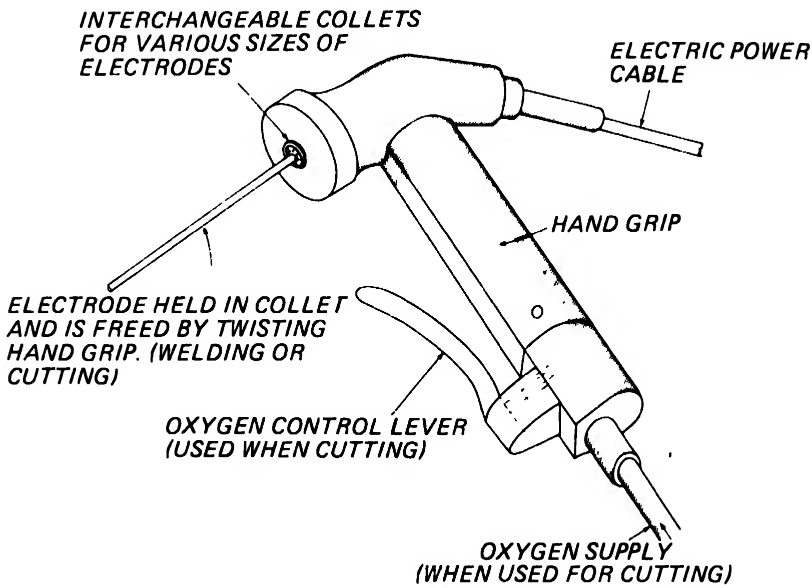
After welding, the joints are subject to X-ray or ultra-sonic testing according to the welding codes used.

Coffer dam

A coffer dam is a watertight case of steel piling erected around a given point to keep out the water. By pumping the dam dry, welding can be performed at atmospheric pressure up to about 18 m deep and welding can proceed irrespective of the state of the tides if in tidal water.

In this case the welding is performed exactly as if it were on shore and the welders are in audio and visual contact with the welding process engineer. Much of the damage to offshore platforms is in the splash zone so there is quite a saving in cost using this method as opposed to hyperbaric welding. Fig. 12.23 shows a typical underwater torch, which can also be used with small modifications for underwater cutting.

Fig. 12.23. Underwater welding (and cutting) torch



13

*Oxy-acetylene welding**

Principles and equipment

(See also pp. 665–7 for general safety precautions)

For oxy-acetylene welding, the oxygen is supplied from steel cylinders and the acetylene either from cylinders or from an acetylene generator which can be of the medium-pressure or low-pressure type.

With cylinder gas, the pressure is reduced to 0.06 N/mm^2 or under, according to the work, by means of a pressure-reducing valve and the acetylene is passed to the blowpipe where it is mixed with oxygen in approximately equal proportions, and finally passed into the nozzle or tip to be burnt.

The medium-pressure acetylene generator delivers gas to any desired pressure up to a maximum of 0.06 N/mm^2 (0.6 bar) in the same way as cylinder gas.

The low-pressure generator produces gas at a pressure of only a few millimetres water column, necessitating the use of 'injector' blowpipes where the high-pressure oxygen injects or sucks the acetylene into the blowpipe. In some cases, as for example if the supply pipes are small for the volume of gas to be carried or if it is desirable to use the equal pressure type of blowpipe, a booster is fitted to the low-pressure generator and the gas pressure increased to 0.06 N/mm^2.

Without Home Office approval, the maximum pressure at which acetylene may be used in England is 0.06 N/mm^2. With approval, the pressure may be increased to 0.15 N/mm^2, but this is rare and applies only in special cases.

Oxygen

The oxygen for both high- and low-pressure systems is supplied in solid drawn steel cylinders at pressures up to 200 bar at 15 °C. The

* See also Appendix 17.

cylinders are rated according to the amount of gas they contain, varying from 0.68 m^3 at a pressure of 137 bar to 9.66 m^3 at 200 bar.

The volume of oxygen contained in the cylinder is approximately proportional to the pressure; hence for every 10 litres of oxygen used, the pressure drops about 0.02 N/mm^2. This enables us to tell how much oxygen remains in a cylinder. The oxygen cylinder is provided with a valve threaded right hand and is painted black. On to this valve, which contains a screw-type tap, the pressure regulator and pressure gauge are screwed. The regulator adjusts the pressure to that required at the blowpipe. Since grease and oil can catch fire spontaneously when in contact with pure oxygen under pressure, they must never be used on any account upon any part of the apparatus. Leakages of oxygen can be detected by the application of a soap solution, when the leak is indicated by the soap bubbles. Never test for leakages with a naked flame.

Liquid oxygen

Liquid oxygen, nitrogen, argon and LPG are available in bulk supply from tankers to vacuum-insulated evaporators (VIE) in which the liquid is stored at temperatures of -160 to -200 C and are very convenient for larger industrial users.

There is no interruption in the supply of gas nor drop in pressure during filling.

The inner vessel, of austenitic stainless steel welded construction, has dished ends and is fitted with safety valve and bursting disc and is available in various sizes with nominal capacities from 844 to 33 900 m^3. Nominal capacity is the gaseous equivalent of the amount of liquid that the vessel will hold at atmospheric pressure. The outer vessel is of carbon steel and fitted with pressure release valve. The inner vessel is vacuum and pearlite insulated from the outer vessel, thus reducing the thermal conductivity to a minimum. The inner vessel *A* (Fig. 13.1) contains the liquid with gas above, and gas is withdrawn from the vessel through the gaseous withdrawal line *B* and rises to ambient temperature in the superheater-vaporizer *C*, from which it passes to the supply pipeline. If the pressure in the supply falls below the required level the pressure control valve *D* opens and liquid flows under gravity to the pressure-raising vaporizer *E*, where heat is absorbed from the atmosphere, and the liquid vaporizes and passes through the gas withdrawal point *H* raising the pressure to the required pre-set level which can be up to 1.7 N/mm^2 (250 lbf/in^2), and the valve *D* then shuts.

In larger units, to allow for heavy gas demand, when the pressure falls on the remote side of the restrictive plate *F*, liquid flows from the vessel via the withdrawal line *G* and passes to the superheater-vaporizer where it changes

to the gaseous form and is heated to ambient temperature, finally passing to the pipeline.

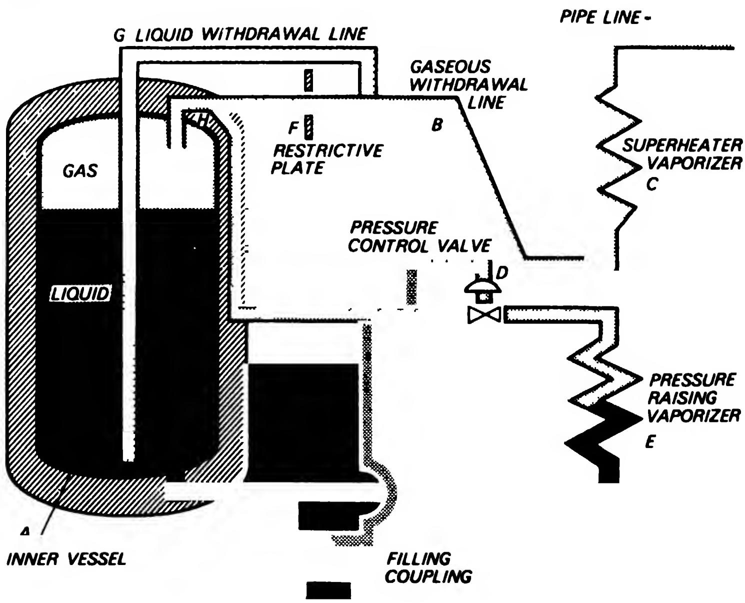
During periods when the VIE is not in use the valve *D* remains shut. Heat from the outside atmosphere gradually flows through the insulation between the vessels so that more liquid is vaporized and the pressure of the gas rises. This rate of heat leakage is slow, however, and it usually takes about seven days for the pressure to rise sufficiently to lift the safety valve, so that under normal working conditions there is almost zero loss

High-pressure acetylene*

In the high-pressure system the acetylene is stored in steel cylinders similar to the oxygen cylinders. Acetylene gas, however, is unstable when compressed to high pressures, and because of this it is contained in the bottles dissolved in a chemical called acetone; hence the name 'dissolved acetylene'.

The acetone is contained in a porous spongy mass of a substance such as charcoal, asbestos, kapok or other such material. Acetone can absorb 25 times its own volume of acetylene at normal temperature and pressure and

Fig. 13.1. Vacuum insulated evaporator.



* Appendix 17 describes the low- and medium-pressure generation and the purification of acetylene.

in the material and the explosive (e.g. PETN) can be of pre-fabricated shape and is relatively cheap. The charge is fired electrically from a fuse head on the inner end of the charge and initiates the explosion, the detonation front then passing progressively through the charge.

The size of the charge depends upon the following variables: surface finish, angle of inclination of tube and plate, yield strength and melting point of the materials, the tube thickness and diameter; and the upper limit of the explosive is dependent upon the size of ligament of the tube plate between tubes, this usually being kept to a minimum in the interest of efficient heat exchange.

The tube plate is tapered towards the outer surface otherwise there would be a bulge in the tube on the inner side after welding and the tube would be difficult to remove. The charge must be fired from the inner end so that the weld will progress from contact point of tube and plate and thus the detonator wires must pass backwards along the charge to the outer end of the tube, the charge being withn a polythene insert **(Fig. 12.20*a*).**

Upon initiation of the explosion, tube and tube plate collide at the inner end of the taper and, due to the release of energy, proceed along it, and ideally the jet of molten metal formed at the collision point is ejected at the tube mouth. In effect the welded surfaces assume a sinusoidal wave form, some of the molten metal, which is rather porous and brittle, being entrapped in the troughs and crests of the wave. This entrapment can be reduced to a minimum by having a good surface finish (e.g. of the order of 0.003 mm) and the angle between tube and tube plate from 10 to 15 . At the lower angle the waves are pronounced and of shorter wavelength while at the higher angle the wavelength is longer and the waves more undulating so that 15 is the usual angle **(Fig. 12.20*b* and *c*).**

Surface oxide and impurities between the surfaces increase the charge required compared with a smooth surface and the positioning of the charge is important. If it is too far in, the energy at the mouth of the tube is not sufficient to produce a weld in this region, while if the charge is not far enough in the tube, welding is not commenced until some distance along the taper. To position the charge correctly and quickly a polythene insert has been developed to contain the charge and is positioned by a brass plug.

At present tubes of any thickness and of diameters 16 57 mm are weldable, with plate thickness greater than 32 mm and 9.5 mm plate ligaments.

The plug for explosive plugging of leaking tubes is of tubular form, the end of which is swaged to give the necessary taper, the polythene insert protruding beyond the open end of the plug to allow for extraction in case of misfire, thus increasing the safety factor **(Fig. 12.21).**

Fig. 12.20

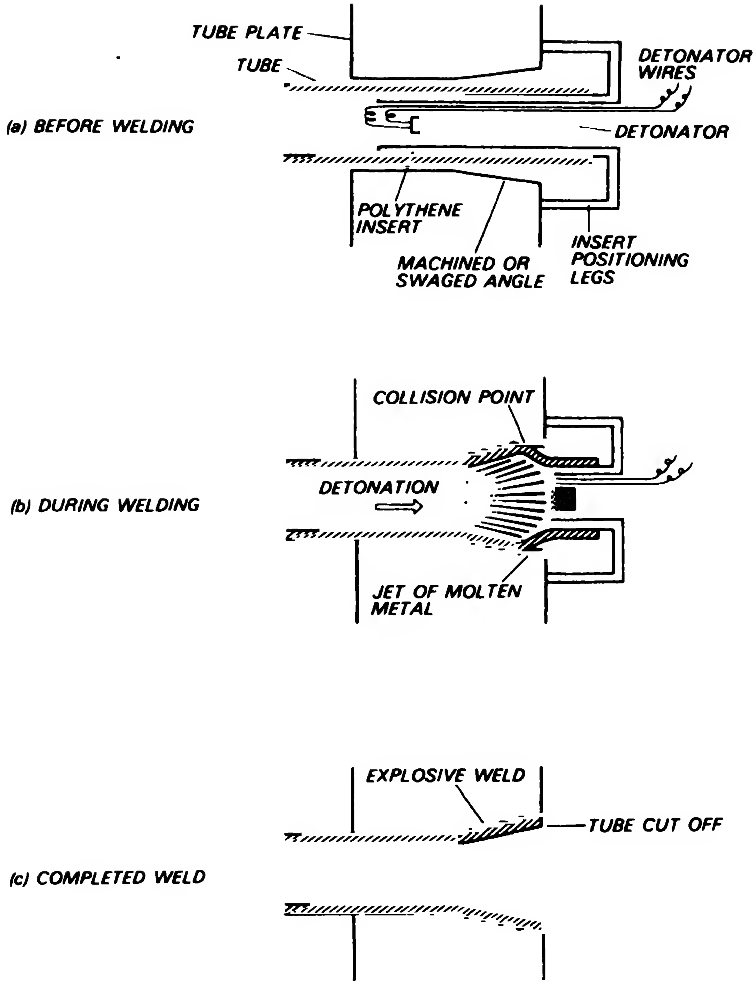
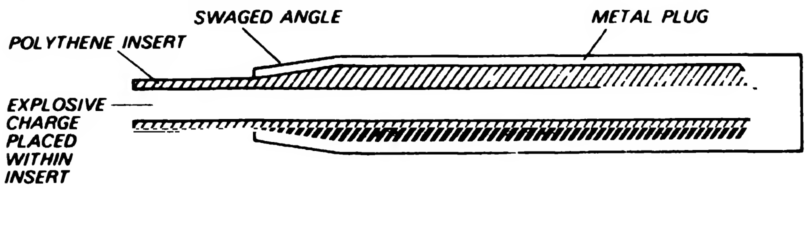


Fig. 12.21. A swaged explosive plug



Since all the configuration is confined to the plug, the tube plate hole is cleaned by grinding, the plug with explosive charge is inserted and the detonator wires connected. The plugs are available in diameters with 1.5 mm increments.

This method has proved very satisfactory in reducing the time and cost in repair work of this nature.

Personnel can be trained by the manufacturers or trained personnel are available under contract.

Gravity welding

This is a method for economically welding long fillets in the flat position using gravity to feed the electrode in and to traverse it along the plate. The equipment is usually used in pairs, welding two fillets at a time, one on each side of a plate, giving symmetrical welds and reducing stress and distortion. The electrode holder is mounted on a ball-bearing carriage and slides smoothly down a guide bar, the angle of which to the weld can be adjusted to give faster or slower traverse and thus vary the length of deposit of the electrode and the leg length of the weld.

The special copper alloy electrode socket is changed for varying electrode diameters and screws into the electrode holder, the electrode being pushed into a slightly larger hole in the socket and held there by the weight of the carriage. Turning the electrode holder varies the angle of electrode inclination. The base upon which the guide and support bar is mounted has two small ball bearings fitted so that it is easy to move along the base plate when resetting. If the horizontal plate is wider than about 280 mm a counterweight can be used with the base, otherwise the base can be attached to the vertical plate by means of two magnets or a jig can be used in place of the base to which the segment is fixed. A flexible cable connects the electrode holder to a disconnector switch carried on the support arm. This enables the current to be switched on and off so that electrodes can be changed without danger of shock. A simple mechanism at the bottom of the guide bar switches the arc off when the carriage reaches the bottom of its travel (Fig. 12.22).

At the present time electrodes up to 700 mm long are available in diameters of 3.5, 4.0, 4.5, 5.0 and 5.5 mm using currents of 220–315 A with rutile, rutile-basic and acid coatings suitable for various grades of steel.

Gravity welding is usually used for fillets with leg lengths of 5–8 mm, the lengths being varied by altering the length of deposit per electrode. An a.c. power source is used for each unit with an OCV of 60 and arc volts about 40 V with currents up to 300 A. Sources are available for supplying up to 6

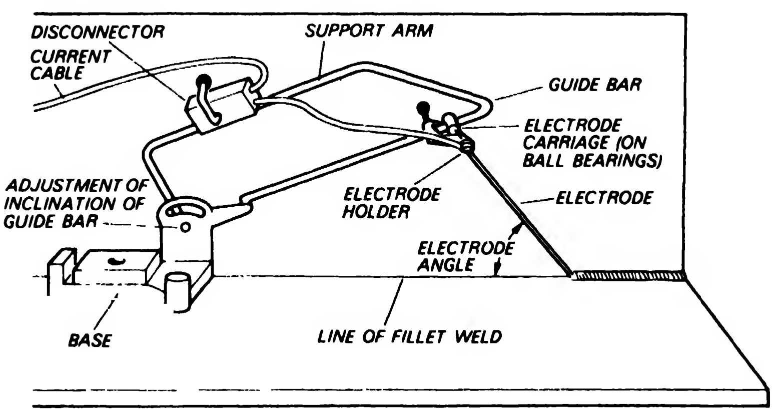
units (three pairs), manageable by one welding operator and so arranged that when the current setting for one unit is chosen, the remaining units are supplied at this value. In general gravity welding is particularly suitable for welding, for example, long parallel stiffeners on large unit panels, enabling one operator to carry out three or four times the deposit length as when welding manually.

Thermit welding

Thermit (or alumino-thermic) is the name given to a mixture of finely divided iron oxide and powdered aluminium. If this mixture is placed in a fireclay crucible and ignited by means of a special powder, the action, once started, continues throughout the mass of the mixture, giving out great heat. The aluminium is a strong reducing agent, and combines with the oxygen from the iron oxide, the iron oxide being reduced to iron.

The intense heat that results, because of the chemical action, not only melts the iron, but raises it to a temperature of about 3000 C. The aluminium oxide floats to the top of the molten metal as a slag. The crucible is then tapped and the superheated metal runs around the parts to be welded, which are contained in a mould. The high temperature of the iron results in excellent fusion taking place with the parts to be welded. Additions may be made to the mixture in the form of good steel scrap, or a small percentage of manganese or other alloying elements, thereby producing a good quality thermit steel. The thermit mixture may consist of about 5 parts of aluminium to 8 parts of iron oxide, and the weight of thermit used will depend on the size of the parts to be welded. The ignition

Fig. 12.22. Gravity welding



powder usually consists of powdered magnesium or a mixture of aluminium and barium peroxide.

Preparation

The ends which are to be welded are thoroughly cleaned of scale and rust and prepared so that there is a gap between them for the molten metal to penetrate well into the joint. Wax is then moulded into this gap, and also moulded into a collar round the fracture. This is important, as it gives the necessary reinforcement to the weld section. The moulding box is now placed around the joint and a mould of fireclay and sand made, a riser, pouring gate and pre-heating gate being included. The ends to be welded are now heated through the pre-heating gate by means of a flame and the wax is first melted from between the ends of the joint. The heating is continued until the ends to be welded are at red heat. This prevents the thermit steel being chilled, as it would be if it came into contact with cold metal. The pre-heating gate is now sealed off with sand and the thermit process started by igniting the powder. The thermit reaction takes up to about 1 minute, depending upon the size of the charge and the additions that have been made in the form of steel scrap and alloying elements etc. When the action is completed the steel is poured from the crucible through the pouring gate, and it flows around the red-hot ends to be welded, excellent fusion resulting. The riser allows extra metal to be drawn by the welded section when contraction occurs on cooling, that is it acts as a reservoir. The weld should be left in the mould as long as possible (up to 12 hours), since this anneals the steel and improves the weld.

Thermit steel is pure and contains few inclusions. It has a tensile strength of about 460 N/mm^2. The process is especially useful in welding together parts of large section, such as locomotive frames, ships' stern posts and rudders, etc. It is also being used in place of flash butt welding for the welding together of rail sections into long lengths.

At the present time British Rail practice is to weld 18 m long rails into lengths of 91 to 366 m at various depots by flash butt welding. These lengths are then welded into continuous very long lengths *in situ* by means of the thermit process and conductor rails are welded in the same way. Normal running rails have a cross-sectional area of 7184 mm^2 and two techniques are employed, one requiring a 7 minute pre-heat before pouring the molten thermit steel into the moulds and the other requiring only 1½ minutes pre-heat, the latter being the technique usually employed. Excess metal can be removed by pneumatic hammer and hot chisel or by portable trimming machine.

Underwater welding

The three main methods of underwater welding at present are (1) wet, (2) localized dry chamber, (3) dry habitat (surroundings).

Wet welding

Wet welding is performed by the diver-welder normally using surface diving or saturation diving techniques using the MMA process with electrodes specially coated with insulating varnishes to keep them dry.

Current is supplied by a generator of some 400 A capacity at 60 100 OCV, directly to the welding torch head. Interchangeable collets of 4 mm and 4.8 mm ($\frac{5}{32}$" and $\frac{3}{16}$"), hold electrodes of these diameters and are tightened by the twist-grip control, which is also used to eject the stub when electrodes are changed. Watertight glands and washers prevent seepage of water into the body of the torch, which is tough rubber covered thus reducing the danger of electric shock.

Arc stability is less than that in air due to the large volumes of gas and steam which are evolved, making vision difficult and as a result touch welding is generally used. The presence of water in the immediate vicinity of the weld except at the molten pool under the arc stream results in the very rapid quenching of the weld metal, which produces a hard, narrow heat affected zone and can give rise to severe hydrogen cracking. At present this method is used for non-critical welds, critical welding being carried out under dry conditions.

Localized dry chamber (hyperbaric)

These chambers, in which welding is performed at pressure above one atmosphere, are generally made of steel and are constructed with antichambers around the section to be welded. Water is then displaced from the chamber by gas pressure. The gas in the chamber used by the diver-welder is typically a mixture of helium and oxygen (heliox). This mixture eliminates the harmful effect of nitrogen, the helium being the carrier for the oxygen – a partial pressure of oxygen above 2 bar can be poisonous. The oxygen content is adjusted until the diver-welder does not use a breathing mask, but at the moment of welding he puts on a breathing–welding mask which has a gas supply separate from that of the chamber and umbilicals connected to the mask to enable the breathing gases to be exhausted outside the chamber.

TIG, MMA and flux cored methods of welding are used down to a depth of 300 m of water but TIG, using high purity argon as the shielding gas, is

the slowest method as it is a low deposition rate process. It can be used for root runs and hot passes, but MMA or the flux cored method is used for filling and capping. Stringer bead techniques may be used to impart toughness, and temper beads to minimize HAZ hardness. Generally the high-strength, basic-coated steel electrodes which may contain iron powder are used. They are pre-heated in a drying oven immediately before use and pre-heat of about 100 C can be applied locally to the joint.

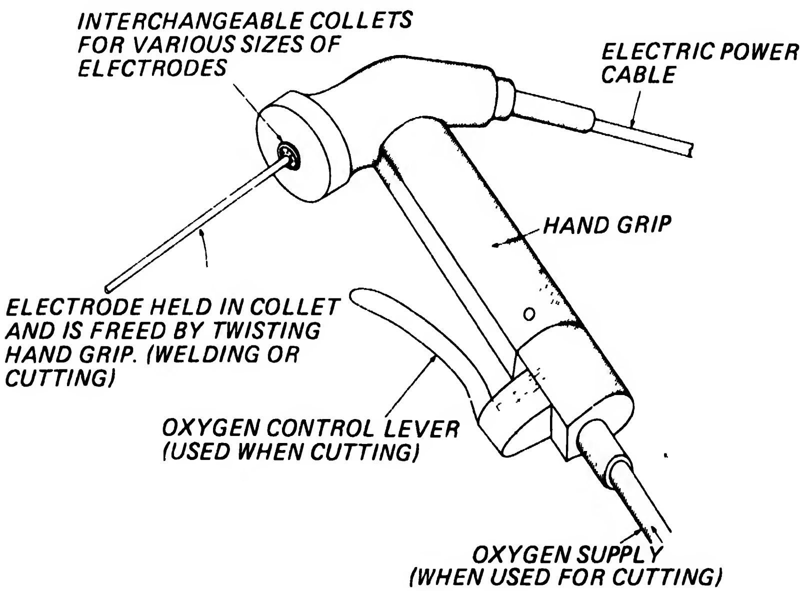
After welding, the joints are subject to X-ray or ultra-sonic testing according to the welding codes used.

Coffer dam

A coffer dam is a watertight case of steel piling erected around a given point to keep out the water. By pumping the dam dry, welding can be performed at atmospheric pressure up to about 18 m deep and welding can proceed irrespective of the state of the tides if in tidal water.

In this case the welding is performed exactly as if it were on shore and the welders are in audio and visual contact with the welding process engineer. Much of the damage to offshore platforms is in the splash zone so there is quite a saving in cost using this method as opposed to hyperbaric welding. Fig. 12.23 shows a typical underwater torch, which can also be used with small modifications for underwater cutting.

Fig. 12.23. Underwater welding (and cutting) torch



13

*Oxy-acetylene welding**

Principles and equipment

(See also pp. 665–7 for general safety precautions)

For oxy-acetylene welding, the oxygen is supplied from steel cylinders and the acetylene either from cylinders or from an acetylene generator which can be of the medium-pressure or low-pressure type.

With cylinder gas, the pressure is reduced to 0.06 N/mm^2 or under, according to the work, by means of a pressure-reducing valve and the acetylene is passed to the blowpipe where it is mixed with oxygen in approximately equal proportions, and finally passed into the nozzle or tip to be burnt.

The medium-pressure acetylene generator delivers gas to any desired pressure up to a maximum of 0.06 N/mm^2 (0.6 bar) in the same way as cylinder gas.

The low-pressure generator produces gas at a pressure of only a few millimetres water column, necessitating the use of 'injector' blowpipes where the high-pressure oxygen injects or sucks the acetylene into the blowpipe. In some cases, as for example if the supply pipes are small for the volume of gas to be carried or if it is desirable to use the equal pressure type of blowpipe, a booster is fitted to the low-pressure generator and the gas pressure increased to 0.06 N/mm^2.

Without Home Office approval, the maximum pressure at which acetylene may be used in England is 0.06 N/mm^2. With approval, the pressure may be increased to 0.15 N/mm^2, but this is rare and applies only in special cases.

Oxygen

The oxygen for both high- and low-pressure systems is supplied in solid drawn steel cylinders at pressures up to 200 bar at 15 °C. The

* See also Appendix 17.

cylinders are rated according to the amount of gas they contain, varying from 0.68 m^3 at a pressure of 137 bar to 9.66 m^3 at 200 bar.

The volume of oxygen contained in the cylinder is approximately proportional to the pressure; hence for every 10 litres of oxygen used, the pressure drops about 0.02 N/mm^2. This enables us to tell how much oxygen remains in a cylinder. The oxygen cylinder is provided with a valve threaded right hand and is painted black. On to this valve, which contains a screw-type tap, the pressure regulator and pressure gauge are screwed. The regulator adjusts the pressure to that required at the blowpipe. Since grease and oil can catch fire spontaneously when in contact with pure oxygen under pressure, they must never be used on any account upon any part of the apparatus. Leakages of oxygen can be detected by the application of a soap solution, when the leak is indicated by the soap bubbles. Never test for leakages with a naked flame.

Liquid oxygen

Liquid oxygen, nitrogen, argon and LPG are available in bulk supply from tankers to vacuum-insulated evaporators (VIE) in which the liquid is stored at temperatures of -160 to -200 C and are very convenient for larger industrial users.

There is no interruption in the supply of gas nor drop in pressure during filling.

The inner vessel, of austenitic stainless steel welded construction, has dished ends and is fitted with safety valve and bursting disc and is available in various sizes with nominal capacities from 844 to 33 900 m^3. Nominal capacity is the gaseous equivalent of the amount of liquid that the vessel will hold at atmospheric pressure. The outer vessel is of carbon steel and fitted with pressure release valve. The inner vessel is vacuum and pearlite insulated from the outer vessel, thus reducing the thermal conductivity to a minimum. The inner vessel A (Fig. 13.1) contains the liquid with gas above, and gas is withdrawn from the vessel through the gaseous withdrawal line B and rises to ambient temperature in the superheater-vaporizer C, from which it passes to the supply pipeline. If the pressure in the supply falls below the required level the pressure control valve D opens and liquid flows under gravity to the pressure-raising vaporizer E, where heat is absorbed from the atmosphere, and the liquid vaporizes and passes through the gas withdrawal point H raising the pressure to the required pre-set level which can be up to 1.7 N/mm^2 (250 lbf/in^2), and the valve D then shuts.

In larger units, to allow for heavy gas demand, when the pressure falls on the remote side of the restrictive plate F, liquid flows from the vessel via the withdrawal line G and passes to the superheater-vaporizer where it changes

to the gaseous form and is heated to ambient temperature, finally passing to the pipeline.

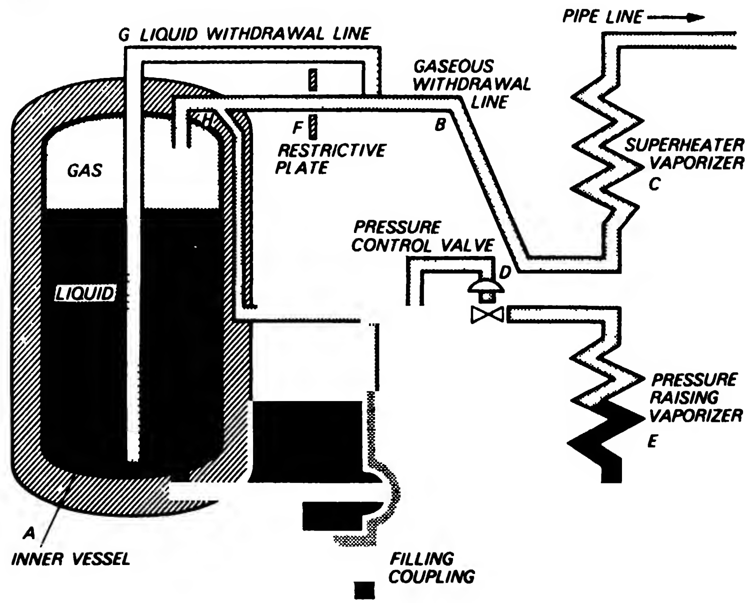
During periods when the VIE is not in use the valve *D* remains shut. Heat from the outside atmosphere gradually flows through the insulation between the vessels so that more liquid is vaporized and the pressure of the gas rises. This rate of heat leakage is slow, however, and it usually takes about seven days for the pressure to rise sufficiently to lift the safety valve, so that under normal working conditions there is almost zero loss.

High-pressure acetylene*

In the high-pressure system the acetylene is stored in steel cylinders similar to the oxygen cylinders. Acetylene gas, however, is unstable when compressed to high pressures, and because of this it is contained in the bottles dissolved in a chemical called acetone; hence the name 'dissolved acetylene'.

The acetone is contained in a porous spongy mass of a substance such as charcoal, asbestos, kapok or other such material. Acetone can absorb 25 times its own volume of acetylene at normal temperature and pressure and

Fig. 13.1. Vacuum insulated evaporator.



* Appendix 17 describes the low- and medium-pressure generation and the purification of acetylene.

for every increase of one atmosphere of pressure (0.1 N/mm^2 or 1 bar) it can absorb an equal amount.

The inlet pressure of the acetylene is usually about 20 bar maximum, typical capacities varying from 0.57 to 8.69 m^3, depending on the cylinder type. The gas leaves the cylinder through a valve after passing through a filter pad. The valve has a screw tap fitted and is screwed left-hand. The cylinder is painted maroon and a regulator (also screwed left-hand) is necessary to reduce the pressure to 1.3 bar maximum as required by the operator.

The amount of dissolved acetylene in a cylinder cannot be determined with any accuracy from the pressure gauge reading since it is in the dissolved condition. The most accurate way to determine the quantity of gas in a cylinder is to weigh it, and subtract this weight from the weight of the full cylinder, which is usually stamped on the label attached to the cylinder. The volume of gas remaining in the cylinder is calculated by remembering that 1 litre of acetylene weighs 1.1 g.

As long as the volume of acetylene drawn from the cylinder is not greater than $\frac{1}{5}$ of its capacity per hour, there is no appreciable amount of acetone contained in gas; hence this rate of supply should not be exceeded. The advantages of dissolved acetylene are that no licence is required for storage of the cylinders, there is no fluctuation of pressure in use, and the gas is always dry, clean and chemically pure, resulting in a reliable welding flame, and it avoids the need to charge and maintain a generator and to dispose of the sludge. There is no discernible difference in efficiency between generated and dissolved acetylene when both are used under normal conditions. Acetylene is highly inflammable and no naked lights should be held near a leaking cylinder, valve or tube. Leaks can be detected by smell or by soap bubbles. If any part of the acetylene apparatus catches fire, immediately shut the acetylene valve on the cylinder. The cylinder should be stored and used in an upright position.

The following is a summary of the main safety precautions to be taken when storing and using cylinders of compressed gas.

Storage

(1) Store in a well ventilated, fire-proof room with flame-proof electrical fittings. Do not smoke, wear greasy clothing or have exposed flames in the storage room.

(2) Protect cylinders from snow and ice and from the direct rays of the sun, if stored outside.

(3) Store away from sources of heat and greasy and oily sources. (Heat increases the pressure of the gas and may weaken the cylinder wall. Oil and grease may ignite spontaneously in the presence of pure oxygen.)
(4) Store acetylene cylinders in an upright position and do not store oxygen and combustible gases such as acetylene and propane together.
(5) Keep full and empty cylinders apart from each other.
(6) Avoid dropping and bumping cylinders violently together.

Use

(7) Keep cylinders away from electrical apparatus or live wires where there may be danger of arcing taking place.
(8) Protect them from the sparks and flames of welding and cutting operations.
(9) Always use pressure-reducing regulators to obtain a supply of gas from cylinders.
(10) Make sure that cylinder outlet valves are clear of oil, water and foreign matter, otherwise leakage may occur when the pressure-reducing regulators are fitted.
(11) Do not use lifting magnets on the cylinders. Rope slings may be used on single cylinders taking due precautions against the cylinder slipping from the sling. Otherwise use a cradle with chain suspension.
(12) Deload the diaphragm of the regulator by unscrewing before fitting to a full cylinder, and open the cylinder valve slowly to avoid sudden application of high pressure on to the regulator.
(13) Do not overtighten the valve when shutting off the gas supply; just tighten enough to prevent any leakage.
(14) Always shut off the gas supply when not in use for even a short time, and always shut off when moving cylinders.
(15) Never test for leaks with a naked flame; use soapy water.
(16) Make sure that oxygen cylinders with round bases are fastened when standing vertically, to prevent damage by falling.
(17) Thaw out frozen spindle valves with hot water NOT with a flame.
(18) Use no copper or copper alloy fitting with more than 70% copper because of the explosive compounds which can be formed when in contact with acetylene.
(19) Do not use oil or grease or other lubricant on valves or other apparatus, and do not use any jointing compound.

(20) Blow out the cylinder outlet by quickly opening and closing the valve before fitting the regulator.

(21) Should an acetylene cylinder become heated due to any cause, immediately take it outdoors, immerse in water or spray it with water, open the valve and keep as cool as possible until the cylinder is empty. Then contact the suppliers.

(22) Do not force a regulator on to a damaged outlet thread. Report damage to cylinders to the suppliers.

Note. Also refer to Form 1704, 'Safety measures required in the use of acetylene gas and in oxy-acetylene processes in factories' (HMSO) and also 'Safety in the use of compressed gas cylinders', a booklet published by the British Oxygen Gases Ltd.

The cylinder outlet union is screwed left hand for combustible gases and right hand for non-combustible gases, the thread being $\frac{5}{8}$ in (16 mm) BSP except for CO_2 which is 21.8 mm, 14 TPI male outlet.

Acetylene (dissolved) is contained in a maroon coloured cylinder with the name ACETYLENE. Oxygen (commercial) is contained in a black coloured cylinder. (See Appendix 6 for a full description of the colour codes used on cylinders (BS 349, BS 381 C).) Consult BS 679, Gas welding filters (GWF) for the correct shade of filter for eye protection and pp. 665–7.

Medium-pressure acetylene generators

The medium-pressure generator uses small granulated carbide. 50 kg of good calcium carbide will produce about 14 000 litres of acetylene, an average practical value being 250 litres of acetylene per kilogram of carbide. See Appendix 17 for a diagram of a medium-pressure generator (Fig. A17.2) and further details.

Owing to the relatively large volume of water into which the small grains of carbide fall, there is no possibility of overheating and the carbide is completely slaked. The sludge, which collects at the bottom of the tank, and is emptied each time that the generator is charged, consists of a thin milky fluid.

The impurities in crude acetylene consist chiefly of ammonia, hydrides of phosphorus, sulphur and nitrogen, and there are also present water vapour and particles of lime.

These impurities must be removed before the gas is suitable for welding use; the gas is filtered and washed and chemically purified by passing it through salts of ferric iron.

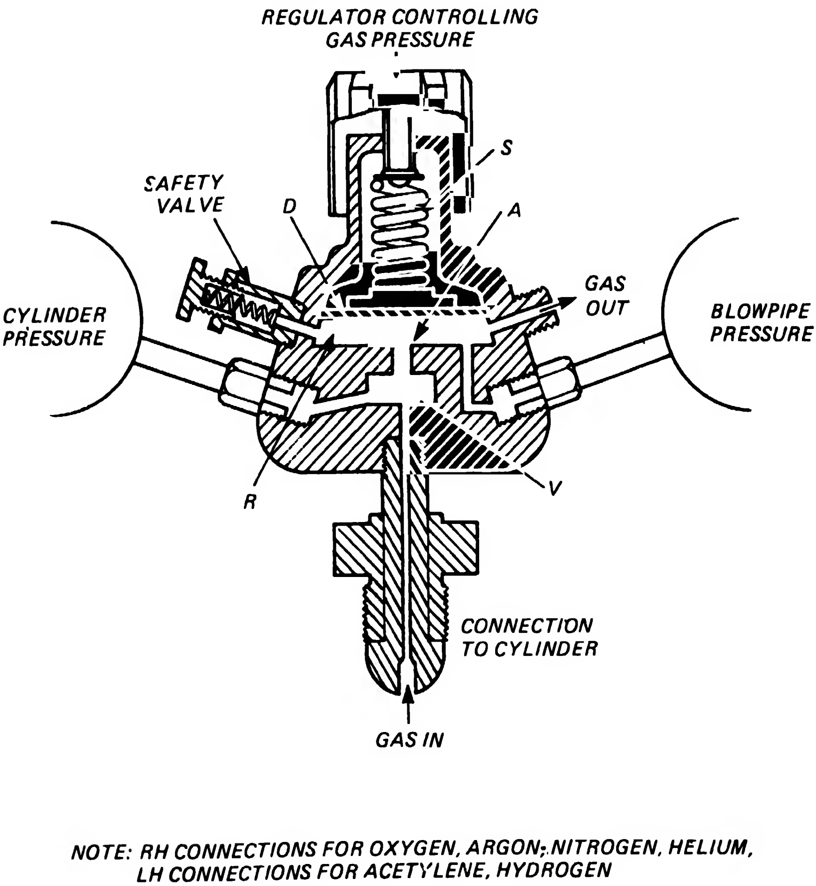
The normal method of testing acetylene to ascertain whether it is being efficiently purified is to hold a silver nitrate test paper (a piece of filter paper soaked in a solution of silver nitrate) in the stream of gas for about 10

seconds. If the acetylene is being properly purified, there will be no trace of stain on the silver nitrate paper.

The reducing valve or pressure regulator

In order to reduce the pressure of either oxygen or dissolved acetylene from the high pressure of the storage cylinder to that required at the blowpipe, a regulator or reducing valve is necessary. Good regulators are essential to ensure the even flow of gas to the blowpipe. A reference to Fig.13.2 will make the principle of operation of the regulator clear. The gas enters the regulator at the base via a fine sintered metal filter and the cylinder pressure is indicated on the first gauge. The gas then enters the body of the regulator *R* through the aperture *A*, which is controlled by the

Fig. 13.2. Pressure regulator (single stage)



valve *V*. The pressure inside the regulator rises until it is sufficient to overcome the pressure of the spring *S*, which loads the diaphragm *D*. The diaphragm is therefore pushed back and the valve *V*, to which it is attached, closes the aperture *A* and prevents any more gas from entering the regulator.

The outlet side is also fitted with a pressure gauge (although in some cases this may be dispensed with) which indicates the working pressure on the blowpipe. Upon gas being drawn off from the outlet side the pressure inside the regulator body falls, the diaphragm is pushed back by the spring, and the valve opens, letting more gas in from the cylinder. The pressure in the body *R* therefore depends on the pressure of the springs and this can be adjusted by means of a regulator as shown.

Regulator bodies are made from brass forgings and single stage regulators are fitted with one safety valve set to relieve pressures of 16–20 bar, and should it be rendered inoperative, as for example by misuse, it ruptures at pressures of 70–80 bar and vents to the atmosphere through a vent in the bonnet. Single-stage regulators are suitable for general welding with maximum outlet pressure of 2.1 bar and for scrap cutting and heavy-duty cutting, thermic lancing and boring with outlet pressures 8.3–14 bar.

Figure 13.3*a*, *b* and *c* shows a two-stage regulator. This reduces the pressure in two stages and gives a much more stable output pressure than the single-stage regulator.

It really consists of two single stages in series within one body forging. The first stage, which is pre-set, reduces the pressure from that of the cylinder to 23 bar, and gas at that pressure passes into the second stage, from which it emerges at a pressure set by the pressure-adjusting control screw attached to the diaphragm. High-pressure regulators except those for acetylene and carbon dioxide are designed for inlet pressures of 230 bar and tested to four times working pressure. A high-flow safety relief valve is fitted and ensures that any abnormal pressures are quickly vented to atmosphere, the valve reseating itself when pressures return to normal. If a safety valve is blowing, the main valve is not seating and the regulator should immediately be taken out of service and sent for overhaul. Needle-type control valves can be fitted to regulator outlets.

The correct blowpipe pressure is obtained by adjusting the pressure of the spring with the control knob and noting the pressure in bar on the blowpipe pressure gauge. On changing a tip the regulator is set with its finger on the tip number on the scale, and final accurate adjustment of the flame is made with the blowpipe regulating valves. This is a simple and convenient method. The regulators are supplied with a table indicating the suitable pressures for various nozzles, which are stamped with their

consumption of gas in litres per minute or suitable numbers. With practice the welder soon recognizes the correct pressures for various tips without reference to the table.

Regulators can be obtained for a wide variety of gases (given here with maximum outlet pressures): oxygen (welding and medium cutting and heating 3.5 bar, heavy cutting and heating 10 bar); acetylene (1.3 bar); argon (3.5 bar); nitrogen (3.5 bar); propane (heavy cutting and heating 3.5 bar); hydrogen (3.5 bar, for pressurizing 10 bar); carbon dioxide (10 bar).

To enable two, three or more cylinders of gas to be connected together, as may be required when heavy cutting work is to be done and the oxygen consumption is very great, special adaptors are available, and these feed the bottles into one gauge. In this way a much steadier supply of oxygen is obtained.

Two operators may also be fed from one cylinder of oxygen or acetylene by using a branched gauge with two regulators. The type of branched gauge which has only one regulator feeding two outlet pipes is not recommended, since any alteration of the blowpipe pressure by one operator will affect the flame of the other operator.

Owing to the rapid expansion of the oxygen in cases where large

Fig. 13.3. (*a*) Passage of gas through a two-stage regulator

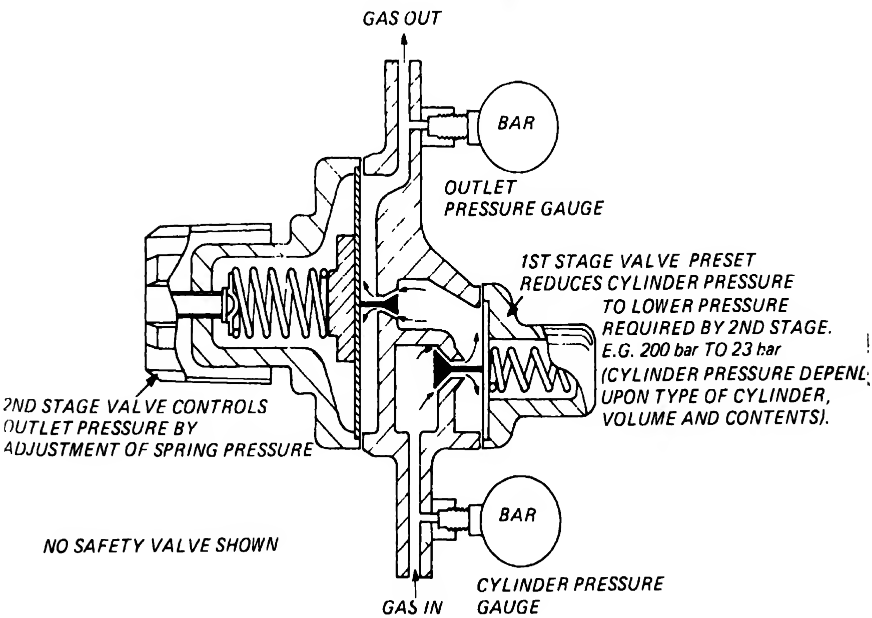
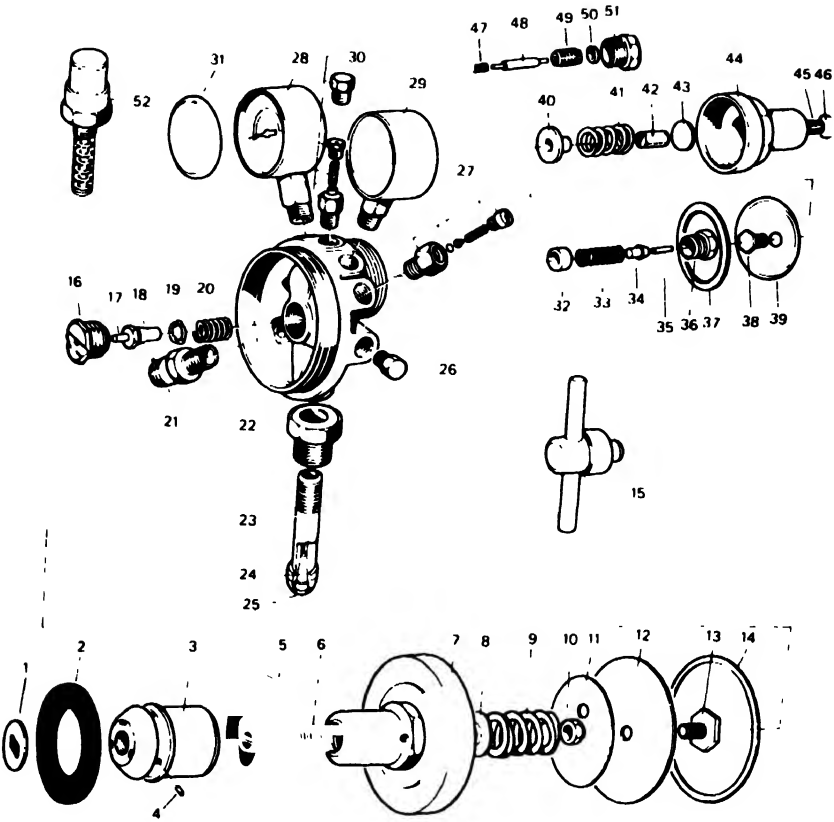


Fig. 13.3. (*b*) Multi-stage regulator



Key

1 Disc monogram	19 Washer	35 Plunger
2 Ring cover	20 Spring	36 Nozzle and seat
3 Knob	21 Outlet adaptor LH	37 Sealing ring
4 Set screw	Outlet adaptor RH	38 Diaphragm carrier
5 Name plate	22 Inlet nut LH	39 Diaphragm
6 Screw P A	Inlet nut RH	40 Disc
7 Bonnet	23 Inlet nipple	41 Spring
8 Spring centre	24 Filter	42 Damper plug
9 Spring	25 Retaining ring	43 Pivot
10 Nut	26 Plug	44 Bonnet
11 Packing plate	27 Safety valve LP	45 Screw
12 Diaphragm	28 Gauge	46 Disc anti-tamper
13 Diaphragm carrier	29 Gauge	47 Spring
14 Washer	30 Relief valve HP	48 Valve
15 Screw P A	31 Gauge glass	49 Seat retainer
16 Nozzle	32 Sleeve	50 Seat
17 Valve pin	33 Spring	51 Valve holder
18 Valve	34 Valve	52 Indicator assembly

Fig. 13.3. (*c*) Two-stage oxygen regulator. Output 0–10 bar.

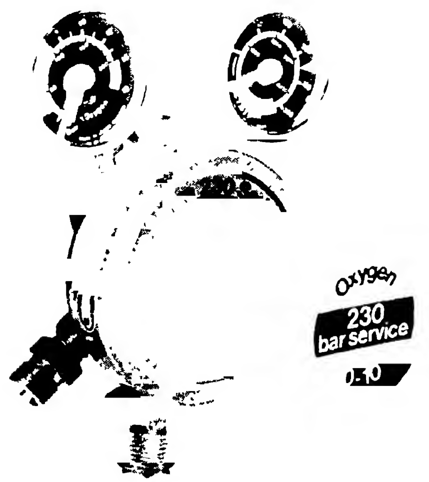
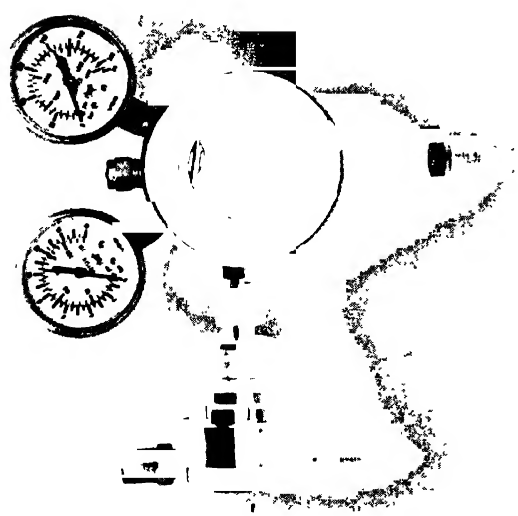


Fig. 13.3. (*d*) Two-stage regulator. 230 bar inlet fitted with resettable flashback arrestor.



quantities are being used, the regulator may become blocked with particles of ice, causing stoppage. This happens most frequently in cold weather, and can be prevented by use of an electric regulator heater. The heater screws into the cylinder and the regulator screws into the heater. The heater is plugged into a source of electric supply, the connexion being by flexible cable.

Hoses

Hoses are usually of a seamless flexible tube reinforced with plies of closely woven fabric impregnated with rubber and covered overall with a tough, flexible, abrasion-resistant sheath giving a light-weight hose. They are coloured blue for oxygen, red for fuel gases, black for non-combustible gases and orange for LPG, Mapp and natural gas. Available lengths are from 5 to 20 m, with bore diameters 4.5 mm for maximum working pressure of 7 bar, 8 mm for a maximum of 12 bar and 10 mm for a maximum working pressure of 15 bar. Nipple- and nut-type connexions and couplers are available for 4.5 mm ($\frac{3}{8}$ in.), 8 and 10 mm hoses with 6.4 mm ($\frac{1}{4}$ in. BSP) and 10 mm ($\frac{3}{8}$ in. BSP) nuts. A hose check valve is used to prevent feeding back of gases from higher or lower pressures and reduces the danger of a flashback due to a blocked nozzle, leaking valve, etc. It is connected in the hose at the blowpipe end or to the economizer or regulator, and consists of a self-aligning spring-loaded valve which seals off the line in the event of backflow. BS 924 J and 796 J apply to hoses.

The welding blowpipe or torch

There are two types of blowpipes: (1) high pressure, (2) low pressure, and each type consists of a variety of designs depending on the duty for which the pipe is required. Special designs are available for rightward and leftward methods of welding (the angle of the head is different in these designs), thin gauge or thick plate, etc., in addition to blowpipes designed for general purposes.

The high-pressure blowpipe is simply a mixing device to supply approximately equal volumes of oxygen and acetylene to the nozzle, and is fitted with regulating valves to vary the pressure of the gases as required (Fig. 13.4*a*, *b*). A selection of shanks is supplied with each blowpipe, having orifices of varying sizes, each stamped with a number or with the consumption in litres per hour (l/h). Various sizes of pipes are available, from a small light variety, suitable for thin gauge sheet, to a heavy duty pipe. A high-pressure pipe cannot be used on a low-pressure system.

The low-pressure blowpipe has an injector nozzle inside its body through which the high-pressure oxygen streams (Fig. 13.5). This oxygen draws the

Fig. 13.4. (*a*) Principle of the high-pressure blowpipe.

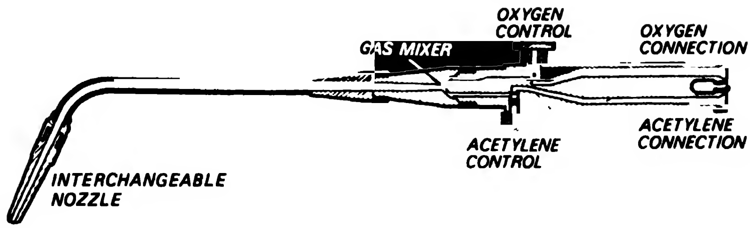
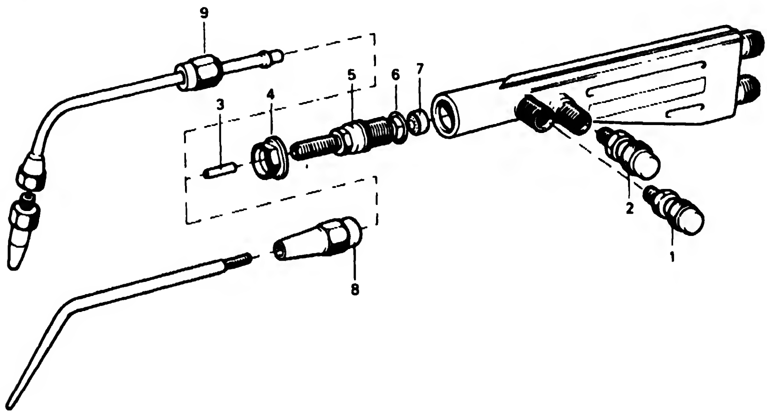


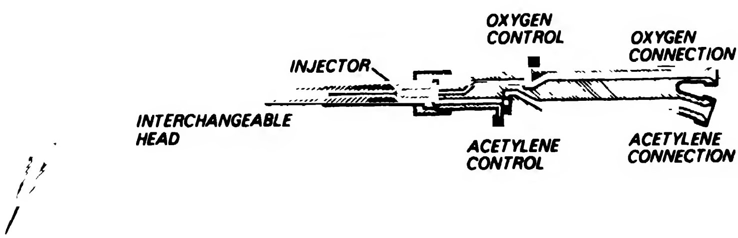
Fig. 13.4. (*b*) Blowpipe.



Key:

1 Spindle assembly RH
2. Spindle assembly LH
3. Insert.
4 Nut-locking.
5. Mixer
6 'O' ring.
7 Mixer spool
8 Adaptor nut
9 Neck assembly

Fig. 13.5. Principle of the low-pressure blowpipe.



low-pressure acetylene into the mixing chamber and gives it the necessary velocity to preserve a steady flame, and the injector also helps to prevent backfiring. The velocity of a 1/1 mixture of oxygen/acetylene may be 200 m per minute, while the maximum gas velocity occurs for a 30% acetylene mixture and may be up to 460 m per min. (These figures are approximate only.)

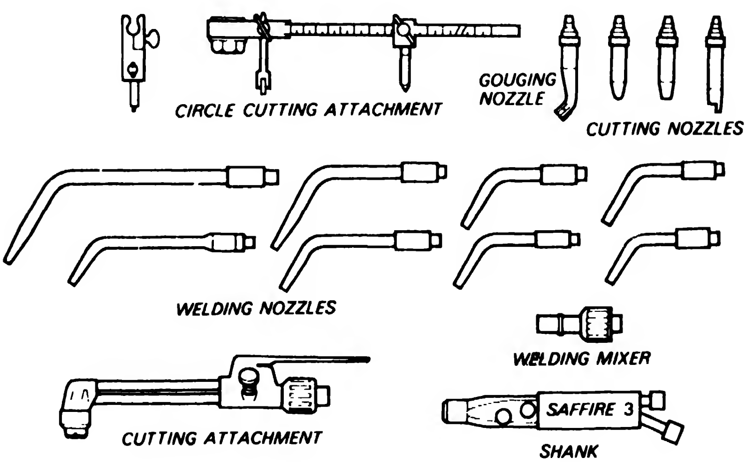
It is usual for the whole head to be interchangeable in this type of pipe, the head containing both nozzle and injector. This is necessary, since there is a corresponding injector size for each nozzle. Regulating valves, as on the high-pressure pipes, enable the gas to be adjusted as required. The low-pressure pipe is more expensive than the high-pressure pipe; and it can be used on a high-pressure system if required, but it is now used on a very small scale.

A very useful type of combined welding blowpipe and metal-cutting torch is shown in Fig. 13.6. The shank is arranged so that a full range of nozzles, or a cutting head, can be fitted. The design is cheaper than for a corresponding separate set for welding and cutting, and the cutter is sufficient for most work.

The oxy-acetylene flame

The chemical actions which occur in the flame have already been discussed on pp. 47–8, and we will now consider the control and regulation of the flame to a condition suitable for welding.

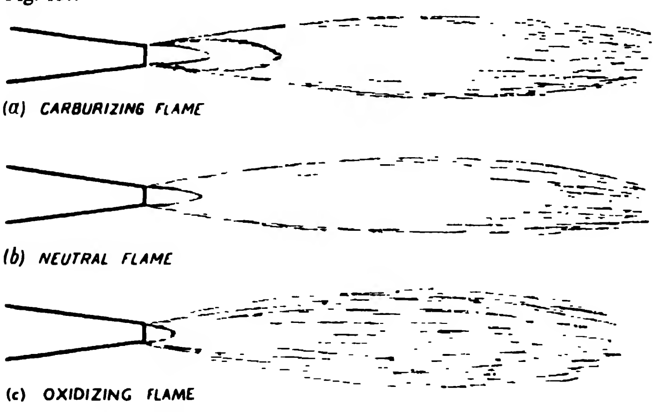
Fig. 13.6. Combined welding and cutting pipes. Will weld sections from 1.6 mm to 32 mm thick, and cut steel up to 150 mm thick with acetylene and 75 mm with propane



Adjustment of the flame.* To adjust the flame to the neutral condition the acetylene is first turned on and lit. The flame is yellow and smoky. The acetylene pressure is then increased by means of the valve on the pipe until the smokiness has just disappeared and the flame is quite bright. The condition gives approximately the correct amount of acetylene for the particular jet in use. The oxygen is then turned on as quickly as possible, and as its pressure is increased the flame ceases to be luminous. It will now be noticed that around the inner blue luminous cone, which has appeared on the tip of the jet, there is a feathery white plume which denotes excess acetylene (Fig. 13.7*a*). As more oxygen is supplied this plume decreases in size until there is a clear-cut blue cone with no white fringe (Fig. 13.7*b*). This is the neutral flame used for most welding operations. If the oxygen supply is further increased, the inner blue cone becomes smaller and thinner and the outer envelope becomes streaky; the flame is now oxidizing (Fig. 13.7*c*). Since the oxidizing flame is more difficult to distinguish than the carbonizing or carburizing (excess acetylene) flame, it is always better to start with excess acetylene and increase the oxygen supply until the neutral condition is reached, than to try to obtain the neutral flame from the oxidizing condition.

Some welders prefer to regulate the oxygen pressure at the regulator itself. The acetylene is lighted as before, and with the oxygen valve on the blowpipe turned full on, the pressure is adjusted correctly at the regulator until the flame is neutral. In this way the welder is certain that the regulator is supplying the correct pressure to the blowpipe for the particular nozzle being used.

Fig. 13.7



* The pressure on oxygen and acetylene gauges is approximately that given in the table on p. 618.

Selection of correct nozzle. As the thickness of the work to be welded increases, the flame will have to supply more heat, and this is made possible by increasing the size of the nozzle. The nozzle selected may cover one or two thicknesses of plate; for example, a nozzle suitable for welding 6.4 mm plate will weld both 4.8 mm and 8 mm plate by suitable regulation of the pressure valves. This is because the blowpipe continues to mix the gases in the correct proportion over a range of pressures. If, however, one is tempted to weld a thickness of plate with a nozzle which is too large, by cutting down the supply of gas at the valves instead of changing the nozzle for one smaller, it will be noticed that explosions occur at the nozzle when welding, these making the operation impossible. These explosions indicate too low a pressure for the nozzle being used.

If, on the other hand, one attempts to weld too great a thickness of metal with a certain nozzle, it will be noticed that as one attempts to increase the pressure of the gases beyond a certain point to obtain a sufficiently powerful flame, the flame leaves the end of the nozzle. This indicates too high a pressure and results in a *hard* noisy flame. It is always better to work with a soft flame which is obtained by using the correct nozzle and pressure. Thus, although there is considerable elasticity as to the thickness weldable with a given nozzle, care should be taken not to overtax it.

Use and care of blowpipe

Oil or grease should upon no account be used on any part of the blowpipe, but a non-oily graphite may be used and is useful for preventing wear and any small leaks.

A backfire is the appearance of the flame in the neck or body of the blowpipe and which rapidly extinguishes itself.

A flashback is the appearance of the flame beyond the blowpipe body into the hose and even the gauge, with subsequent explosion. It can be prevented by fitting a flashback arrestor.

Backfiring may occur at the pipe through several causes:

(1) Insufficient pressure for the nozzle being used. This can be cured by increasing the pressure on the gauge.

(2) Metal particles adhering to the nozzle. The nozzle can be freed of particles by rubbing it on a leather or wooden surface. (The gases should be first shut off and then relit.)

(3) The welder touching the plate or weld metal with the nozzle. In this case the gases should be shut off and then relit.

(4) Overheating of the blowpipe. A can of water should be kept near so as to cool the nozzle from time to time, especially when using a large flame. Oxygen should be allowed to pass slowly through the

nozzle, when immersed in the water, to prevent the water entering the inside of the blowpipe.

(5) Should the flame backfire into the mixing chamber with a squealing sound, and a thin plume of black smoke be emitted from the nozzle, serious damage will be done to the blowpipe unless the valves are immediately turned off. This fault may be caused by particles having lodged inside the pipe, or even under the regulating valves. The pipe should be thoroughly inspected for defects before being relit.

In the event of a backfire, therefore, immediately shut off the acetylene cylinder valve, and then the oxygen, before investigating the cause.

Blowpipe nozzles should be cleaned by using a soft copper or brass pin. They should be taken off the shank and cleaned from the inside, as this prevents enlarging the hole. A clean nozzle is essential, since a dirty one gives an uneven-shaped flame with which good welds are impossible to make. Special sets of reamers can be obtained for this work.

Flashback arrestor

Note. Flashback arrestors should be fitted to all welding equipment. A flashback occurs when the flame moves from the blow torch into the supply system against the flow of the gases. It is potentially dangerous and its effects can range from sooty deposits in the blowpipe and hoses to a fire in the gauge or cylinder often accompanied by squealing or popping noises. It is generally due to incorrect operating practice such as overheated blowpipe and wrong pressures.

The automatic flashback arrestor is made for acetylene, propane, hydrogen, and oxygen and is generally connected to the regulator outlet (Fig. 13.3*c*)and prevents flame movement into gauges and cylinder, causing regulator damage and even cylinder fires.

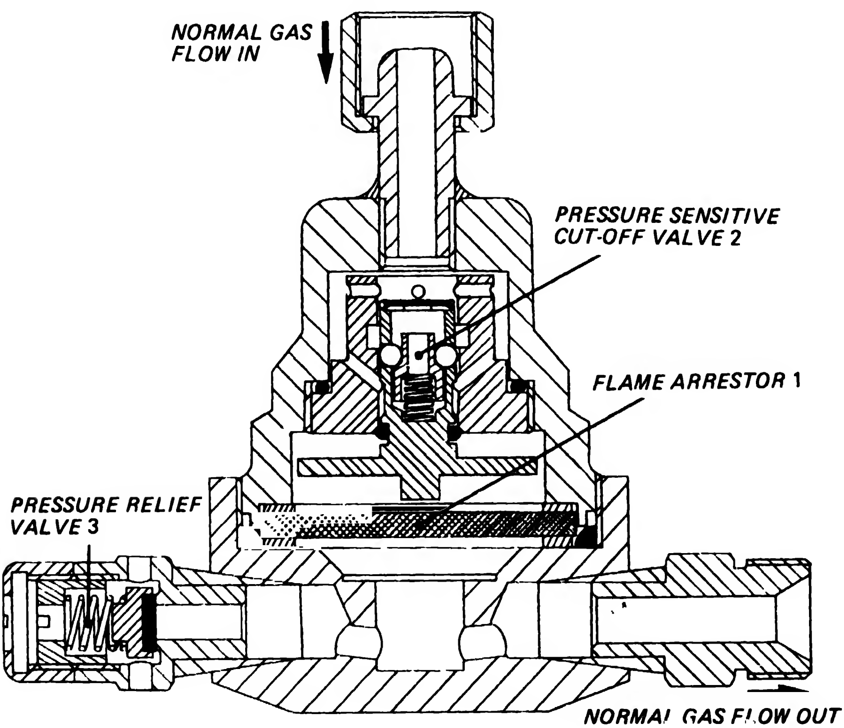
A dense sintered stainless steel plate filter of up to 100 micron mesh (1) in Fig.13.8*a* arrests the flame and is designed to quench the flame from even the most violent explosion of the gas mixture. The large surface area of the filter does not offer much resistance to the forward flow of the gas. The pressure-sensitive cut-off valve (2) automatically cuts off the supply of gas to the blow torch preventing sustained flashback and it will remain closed until it is set manually, a spring plus the gas pressure holding it closed. There should never be any attempt to reset the valve until the cause of the flashback has been thoroughly investigated and put right and it cannot be reset until the pressure is taken off the system, so close the cylinder valve to cut off the supply at source. To reset, on the model shown, the reset pin (attached to the gauge by a chain to prevent loss) is inserted into the gas

inlet orifice, centred against the valve and pushed hard home resetting the valve mechanism. On some models there is a visible lever which is actuated when the arrestor cut-off valve operates. This lever actuates the mechanism but should never be reset until the cause of the flashback is determined and put to rights.

After several actuations, carbon deposits may interfere with the correct functioning of the arrestor so it should be exchanged. Arrestors are generally used up to oxygen pressures of 10 bar, propane of 5 bar and acetylene of 1.5 bar.

Operation. The spring-loaded valve (or piston) is held by a low melting point solder against the tension of a spring. If a flashback occurs the temperature rising to 120–150 °C melts the solder and the non-return valve is forced onto its seat and prevents further reverse flow of gas. There is little restriction of gas flow under normal working conditions but in the case of the piston being activated the whole unit must be replaced (Figs. 13.8*b*, *c*).

Fig. 13.8. (*a*) Section through resettable flashback arrestor.



Technique of welding

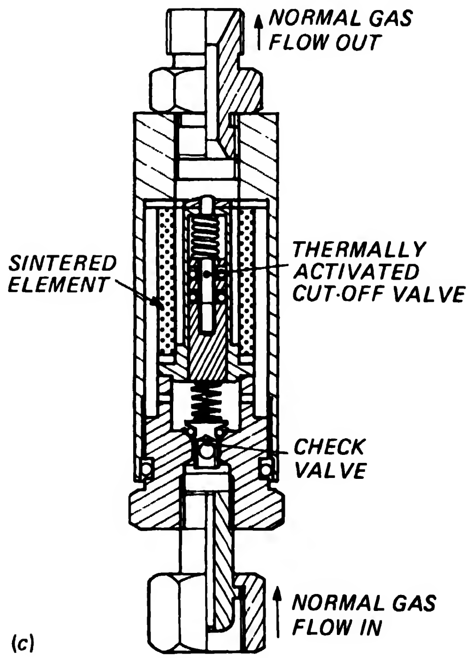
Before attempting any actual welding operations, the beginner should acquire a sense of fusion and a knowledge of blowpipe control. This can be obtained by running lines of fusion on thin-gauge steel plate.

The flame is regulated to the neutral condition and strips of 1.6 or 2 mm steel plate are placed on firebricks on the welding bench. Holding the blowpipe at approximately 60° to the plate, with the inner blue cone near the metal surface, and beginning a little from the right-hand edge of the sheet, the metal is brought to the melting point and a puddle formed with a rotational movement of the blowpipe. Before the sheet has time to melt through into a hole, the pipe is moved steadily forward, still keeping the steady rotating motion, and the line of fusion is made in a straight line. This exercise should be continued on various thicknesses of thin-gauge plate until an even line is obtained, and the underside shows a regular continuous bead, indicating good penetration, the student thus acquiring a sense of fusion and of blowpipe control.

In the following pages various methods of welding techniques are considered, and it would be well to state at this point what constitutes a good weld, and what features are present in a bad weld.

Fig. 13.8. (*b*) Heavy duty high flow flashback arrestor, thermally operated. (*c*) Section through flashback arrestor

(*b*)



(*c*)

Fig. 13.9*a* indicates the main features of a good fusion weld, with the following features:

(*a*) Good fusion over the whole side surface of the V.
(*b*) Penetration of the weld metal to the underside of the parent plate.
(*c*) Slight reinforcement of the weld above the parent plate.
(*d*) No entrapped slag, oxide, or blowholes.

Fig. 13.9*b* indicates the following faults in a weld:

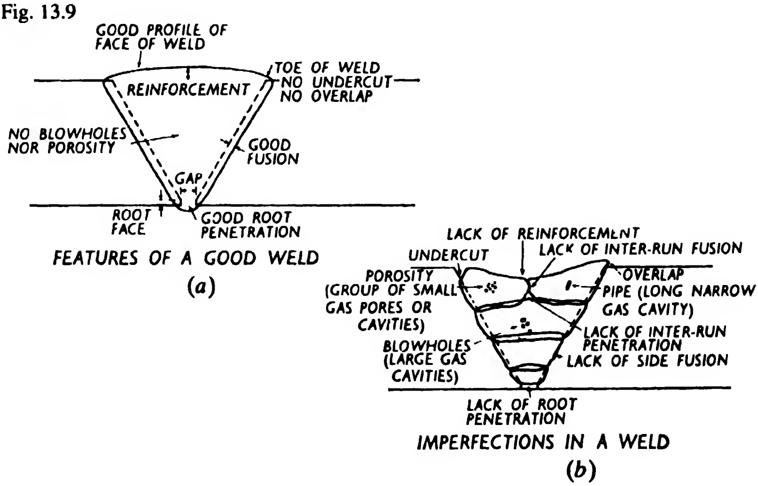
(*a*) Bad flame manipulation and too large a flame has caused molten metal to flow on to unfused plate, giving no fusion (i.e. adhesion).
(*b*) Wrong position of work, incorrect temperature of molten metal, and bad flame manipulation has caused slag and oxide to be entrapped and channels may be formed on each line of fusion, causing undercutting.
(*c*) The blowpipe flame may have been too small, or the speed of welding too rapid, and this with lack of skill in manipulation has caused bad penetration.

(N.B. Reinforcement on the face of a weld *will not* make up for lack of penetration.)

Methods of welding

The following British Standards apply to this section: BS 1845, *Filler alloys for brazing*; BS 1723, *Brazing*; *Part 1 Specification for brazing*, *Part 2 Guide to brazing*; BS 1724, *Bronze welding by gas*; BS 1453, *Filler materials for gas welding* (*ferritic steels, cast iron, austenitic stainless steels, copper and copper alloys, aluminium and aluminium alloys and magnesium alloys*); BS 1821, *Class 1 oxy-acetylene welding of ferritic steel*

Fig. 13.9



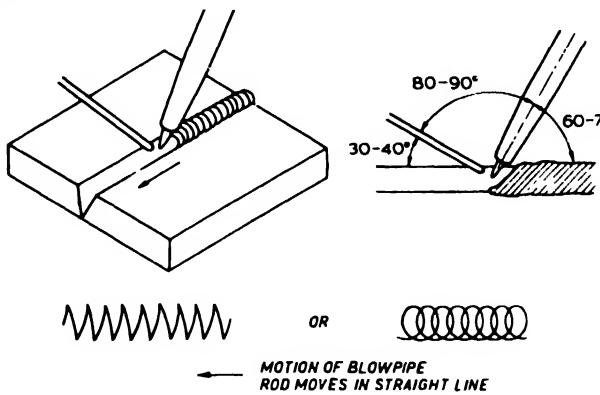
pipework for the carrying of fluids; BS 2640, *Class 2 oxy-acetylene welding of carbon steel pipework for carrying fluids.*

Leftward or forward welding

This method is used nowadays for welding steel plate under 6.5 mm thick and for welding non-ferrous metals. The welding rod precedes the blowpipe along the seam, and the weld travels from right to left when the pipe is held in the right hand. The inner cone of the flame, which is adjusted to the neutral condition, is held near the metal, the blowpipe making an angle of 60 to 70° with the plate, while the filler rod is held at an angle of 30 to 40°. This gives an angle of approximately 90° between the rod and the blowpipe. The flame is given a rotational, circular, or side-to-side motion, to obtain even fusion on each side of the weld. The flame is first played on the joint until a molten pool is obtained and the weld then proceeds, the rod being fed into the molten pool and not melted off by the flame itself. If the flame is used to melt the rod itself into the pool, it becomes easy to melt off too much and thus reduce the temperature of the molten pool in the parent metal to such an extent that good fusion cannot be obtained. Fig. 13.10 will make this clear.

The first exercise in welding with the filler rod is done with the technique just described and consists of running lines of weld on 1.6 or 2 mm plate, using the filler rod. Butt welds of thin plate up to 2.4 mm can be made by flanging the edges and melting the edges down. When a uniform weld is obtained, with good penetration, the exercises can be repeated on plate up to 3.2 mm thick, and butt welds on this thickness attempted. Above 3.2 mm thick, the plates are bevelled, chamfered, or V'd to an angle of 80 to 90 (Fig. 13.11). The large area of this V means that a large quantity of weld metal is required to fill it. If, however, the V is reduced to less than 80 , it is found

Fig. 13.10. Leftward welding

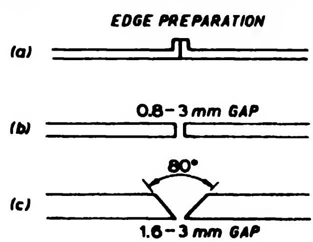


that as the V becomes narrower the blowpipe flame tends to push the molten metal from the pool, forward along onto the unmelted sides of the V, resulting in poor fusion or adhesion. This gives an unsound weld, and the narrower the V the greater this effect.

As the plate to be welded increases in thickness, a larger nozzle is required on the blowpipe, and the control of the molten pool becomes more difficult; the volume of metal required to fill the V becomes increasingly greater, and the size of nozzle which can be used does not increase in proportion to the thickness of the plate, and thus welding speed decreases. Also with thicker plates the side-to-side motion of the blowpipe over a wide V makes it difficult to obtain even fusion on the sides and penetration to the bottom, while the large volume of molten metal present causes considerable expansion. As a result it is necessary to weld thicker plate with two or more layers if this method is used. From these considerations it can be seen that above 6.4 mm plate the leftward method suffers from several drawbacks. It is essential, however, that the beginner should become efficient in this method before proceeding to the other methods, since for general work, including the non-ferrous metals (see later), it is the most used.

Edge preparation (Letters refer to (Fig. 13.11)	Thickness of plate (mm)	Nozzle size (mm)	Oxygen and acetylene pressure (bar)	Oxygen and acetylene gas consumption (l/h)
(*a*)	0.9–1.6	0.9–1	0.14	28
		1.2–2	0.14	57
(*b*)	2.4–3.0	2–3	0.14	86
		2.6–5	0.14	140
(*c*)	3.0–4.0	3.2–7	0.14	200
		4.0–10	0.21	280

Fig. 13.11. Leftward welding. edge preparations.



The preparation of various thicknesses of plate for butt joints by the leftward method is given in the table accompanying Fig. 13.11.

Rightward welding

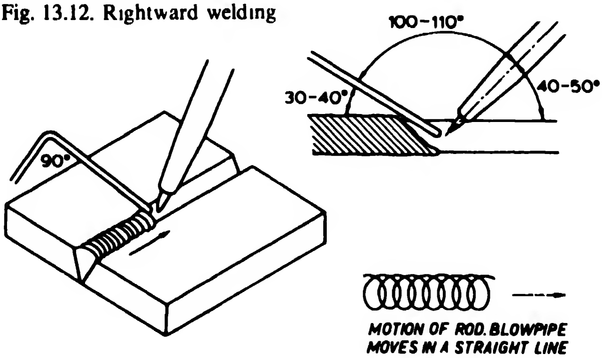
This method was introduced some years ago to compete with electric arc welding in the welding of plate over 4.8 mm thick, since the leftward method has the disadvantage just mentioned on welding thick plate. This method has definite advantages over the leftward method on thick plate, but the student should be quite aware of its limitations and use it only where it has a definite advantage.

In this method the weld progresses along the seam from left to right, the rod following the blowpipe. The rod is given a rotational or circular motion, while the blowpipe moves in practically a straight line, as illustrated in Fig. 13.12. The angle between blowpipe and rod is greater than that used in the leftward method.

When using this method good fusion can be obtained without a V up to 8 mm plate. Above 8 mm the plates are prepared with a 60° V, and since the blowpipe has no side motion the heat is all concentrated in the narrow V, giving good fusion. The blowpipe is pointing backwards towards the part that has been welded and thus there is no likelihood of the molten metal being pushed over any of the unheated surface, giving poor fusion.

A larger blowpipe nozzle is required for a given size plate than in leftward welding, because the molten pool is controlled by the pipe and rod but the pipe has no side to side motion. This larger flame gives greater welding speed, and less filler rod is used in the narrower V. The metal is under good control and plates up to 16 mm thick can be welded in one pass. Because the blowpipe does not move except in a straight line, the molten metal is agitated very little and excess oxidation is prevented. The flame playing on the metal just deposited helps to anneal it, while the smaller volume of molten metal in the V reduces the amount of expansion. In

Fig. 13.12. Rightward welding



addition, a better view is obtained of the molten pool, resulting in better penetration.

It is essential, however, in order to ensure good welds by this method, that blowpipe and rod should be held at the correct angle, the correct size nozzle and filler rod used, and the edges prepared properly (Fig. 13.13). The rod diameter is about half the thickness of the plate being welded up to 8 mm plate, and half the thickness + 0.8 mm when welding V'd plate. The blowpipe nozzle is increased in size from one using about 300 litres per hour, with the leftward method, to one using about 350 litres per hour, when welding 3.2 mm plate. If too large diameter filler rods are used, they melt too slowly causing poor penetration, and poor fusion. Small rods melt too quickly and reinforcement of the weld is difficult. Rightward welding has no advantage on plates below 6.4 mm thick and is rarely used below this thickness, the leftward method being preferred.

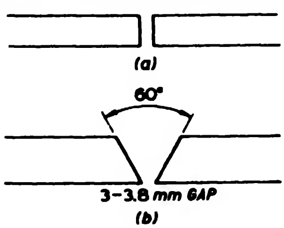
The advantages of the rightward method on thicker plate are:

(1) Less cost per metre run due to less filler rod being used and increased speed.
(2) Less expansion and contraction.
(3) Annealing action of the flame on the weld metal.
(4) Better view of the molten pool, giving better control of the weld.

See later for 'all-position rightward welding'.

Edge preparation (Letters refer to Fig. 13.13)	Thickness of plate (mm)	Nozzle size (mm)	Oxygen and acetylene pressure (bar)	Oxygen and acetylene gas consumption (l/h)
(*a*)	4.8–8.2	5.5–13	0.28	370
		6.5–18	0.28	520
		8.2–25	0.42	710
(*b*)	8.2–15	10–35	0.63	1000
		13–45	0.35 (heavy duty mixer)	1300

Fig. 13.13. Rightward welding: edge preparations.



Vertical welding

The preparation of the plate for welding greatly affects the cost of the weld, since it takes time to prepare the edges, and the preparation given affects the amount of filler rod and gas used. Square edges need no preparation and require a minimum of filler rod. In leftward welding square edges are limited to 3.2 mm thickness and less. In vertical welding, up to 4.8 mm plate can be welded with no V'ing with the single-operator method while up to 16 mm plate can be welded with no V'ing with the two-operator method, the welders working simultaneously on the weld from each side of the plate. The single-operator method is the most economical up to 4.8 mm plate.

The single-operator method (up to 4.8 mm plate) requires more skill in the control of the molten metal than in downhand welding. Welding is performed either from the bottom upwards, and the rod precedes the flame as in the leftward method, or from the top downwards, in which case the metal is held in place by the blowpipe flame. This may be regarded as the rightward method of vertical welding, since the flame precedes the rod down the seam. In the upward method the aim of the welder is to use the weld metal which has just solidified as a 'step' on which to place the molten pool. A hole is first blown right through the seam, and this hole is maintained as the weld proceeds up the seam, thus ensuring correct penetration and giving an even back bead.

In the vertical welding of thin plate where the edges are close together, as for example in a cracked automobile chassis, little filler rod is needed and the molten pool can be worked upwards using the metal from the sides of the weld. Little blowpipe movement is necessary when the edges are close together, the rod being fed into the molten pool as required. When the edges are farther apart, the blowpipe can be given the usual semicircular movement to ensure even fusion of the sides.

From Fig.13.14 it will be noted that as the thickness of the plate increases, the angle of the blowpipe becomes much steeper.

When welding downwards much practice is required (together with the correct size flame and rod), in order to prevent the molten metal from falling downwards. This method is excellent practice to obtain perfect control of the molten pool.

Double-operator vertical welding

The flames of each welder are adjusted to the neutral condition, both flames being of equal size. To ensure even supply of gas to each pipe the blowpipes can be supplied from the same gas supply. It is possible to use much smaller jets with this method, the combined consumption of which is

less than that of a single blowpipe on the same thickness plate. Blowpipes and rods are held at the same angles by each operator, and it is well that a third person should check this when practice runs are being done. To avoid fatigue a sitting position is desirable, while, as for all types of vertical welding, the pipes and tubes should be as light as possible. Angles of blowpipes and rods are shown in **Fig. 13.15.**

This method has the advantage that plate up to 16 mm thick can be welded without preparation, reducing the gas consumption and filler rod used, and cutting out the time required for preparation. When two operators are welding 12.5 mm plate, the gas used by both is less than 50%

Fig. 13.14. Single-operator vertical welding

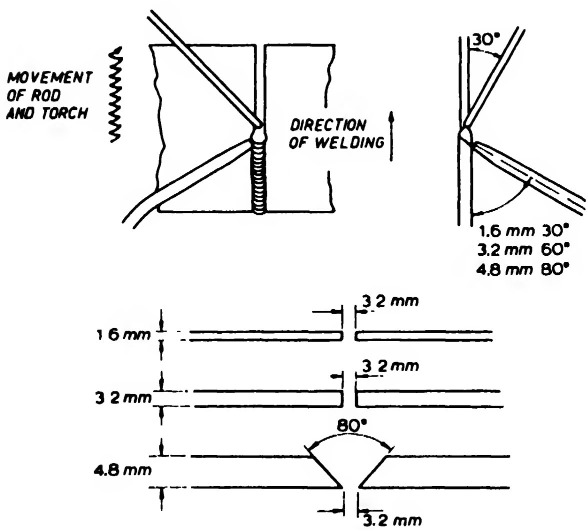
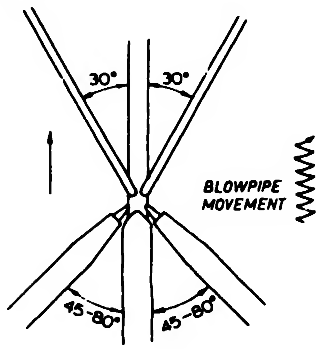


Fig. 13.15. Double-operator vertical welding



of the total consumption of the blowpipe when welding the same thickness by the downhand rightward method. Owing to the increased speed of welding and the reduced volume of molten metal, there is a reduction in the heating effect, which reduces the effects of expansion and contraction.

Overhead welding

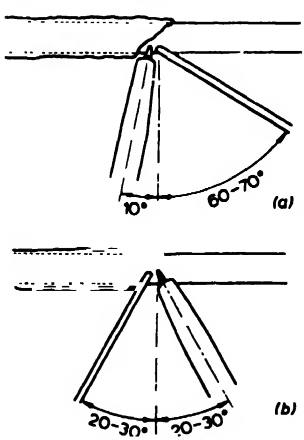
Overhead welding is usually performed by holding the blowpipe at a very steep angle to the plate being welded. The molten pool is entirely controlled by the flame and by surface tension, and holding the flame almost at right angles to the plate enables the pool to be kept in position.

Difficulty is most frequently found in obtaining the correct amount of penetration. This is due to the fact that as sufficient heat to obtain the required penetration is applied, the molten pool becomes more fluid and tends to become uncontrollable. With correct size of flame and rod, however, and practice, this difficulty can be entirely overcome and sound welds made. Care should also be taken that there is no undercutting along the edges of the weld.

A comfortable position and light blowpipe and tubes are essential if the weld is to be made to any fair length, as fatigue of the operator rapidly occurs in this position and precludes the making of a good weld.

The positions of blowpipe and rod for the leftward techniques are shown in Fig. 13.16*a*, while Fig. 13.16*b* shows their relative positions when the rightward method is used. The rightward method is generally favoured, but

Fig. 13.16. (*a*) Leftward overhead welding. The flame is used to position the molten metal. (*b*) Rightward overhead welding Blowpipe has little motion. Rod moves criss-cross from side to side.



it must again be stressed that considerable practice is required for a welder to become skilled in overhead welding.

Lindewelding

This method was devised by the Linde Co. of the United States for the welding of pipelines (gas and oil), and for this type of work it is very suitable. Its operation is based on the following facts:

(1) When steel is heated in the presence of carbon, the carbon will reduce any iron oxide present, by combining with the oxygen and leaving pure iron. The heated surface of the steel then readily absorbs any carbon present.

(2) The absorption of carbon by the steel lowers the melting point of the steel (e.g. pure iron melts at 1500°C, while cast iron with $3\frac{1}{2}\%$ carbon melts at 1130°C).

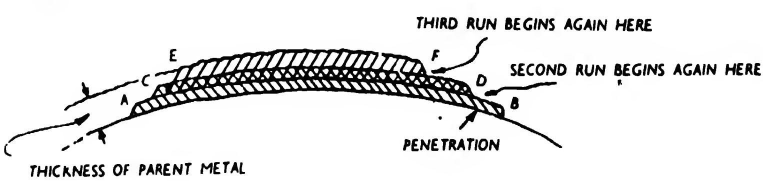
In Lindewelding the carbon for the above action is supplied by using a carburizing flame. This deoxidizes any iron oxide present and then the carbon is absorbed by the surface layers, lowering their melting point. By using a special rod, a good sound weld can be made in this way at increased speed. The method is almost exclusively used on pipe work and is performed in the downhand position only.

Block welding

Block welding is a method especially applicable to steel pipes and thick walled tubes in which the weld is carried out to the full depth of the joint in steps. This can more easily be understood by reference to the figure. The first run is laid giving good penetration for as great a length as is convenient, say *AB* (Fig. 13.17).

The second run is now started a little way short of *A* and finished short of *B*, as *CD*. The third run is laid in a similar manner from *E* to *F*, if required, and so on for the full depth of the weld required. We thus have a series of ledges or platforms at the beginning and end of the weld. The welding is now continued with the first run from *B* with full penetration. The second run starts at *D* and has the ledge *BD* deposited before it gets to where the

Fig. 13.17



first run started. Similarly with the third run, which starts at *F*. Upon completing the weld in the case of a pipe, the first run finishes at *A*, the second one at *C* and the third one at *E*, giving a good anchorage on to the previous run.*

Horizontal–vertical fillet welding

In making fillet welds (**Fig. 13.18**), care must be taken that, in addition to the precautions taken regarding fusion and penetration, the vertical plate is not undercut as in **Fig.13.19*b***, and the weld is not of a weakened section. A lap joint may be regarded as a fillet. No difficulty will be experienced with undercutting, since there is no vertical leg, but care should be taken not to melt the edge of the lapped plate.

The blowpipe and rod must be held at the correct angles. Holding the

Fig. 13.18. Types of fillet joints

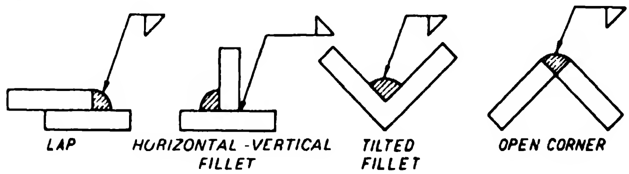


Fig. 13.19. (*a*)

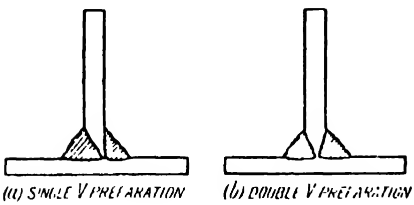
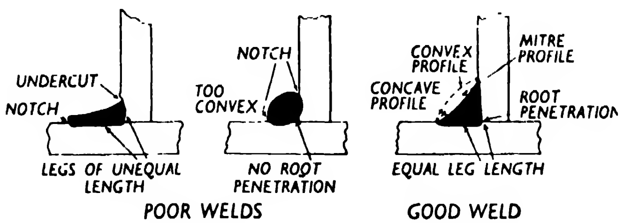


Fig. 13. 19 (*b*)



Refer also to BS 1821 and 2640, *Class I and class II oxy-acetylene welding of steel pipelines and*

flame too high produces undercutting, and the nozzle of the cone should be held rather more towards the lower plate, since there is a greater mass of metal to be heated in this than in the vertical plate (Fig. 13.19*a* and *b*).

Figure 13.20 *a* and *b* show the angles of the blowpipe and rod, the latter being held at a steeper angle than the blowpipe. Fillet welding requires a larger size nozzle than when butt welding the same section plate, owing to the greater amount of metal adjacent to the weld. Because of this, multi-jet blowpipes can be used to great advantage for fillet welding. The single (Fig. 13.19*a*) preparation is used for joints which are subjected to severe loading, while the double V preparation (Fig. 13.19*b*) is used for thick section plate when the welding can be done from both sides. The type of preparation therefore depends entirely on the service conditions, the unprepared joint being quite suitable for most normal work.

All-position rightward welding

This method can be used for vertical, overhead and horizontal–vertical positions, the blowpipe preceding the rod as for downhand welding. For vertical welding the blowpipe is held 10° below the horizontal line (welding upwards) while the rod is held alongside the pipe at 45–60° to the vertical plate. Overhead welding is done similarly. The advantages are similar to those of the downhand position but considerable practice is required to become proficient. See Fig 13.21.

For the preparation and welding of steel pipes the student should refer to BS 1821, *Class I steel pipelines* and BS 2640, *Class II steel pipelines*.

Fig. 13.20. (*a*) Fillet weld.

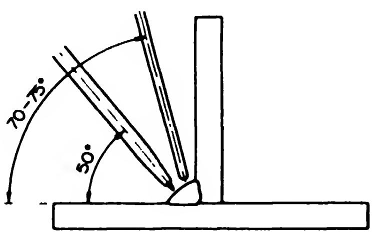


Fig. 13.20. (*b*) Fillet weld.

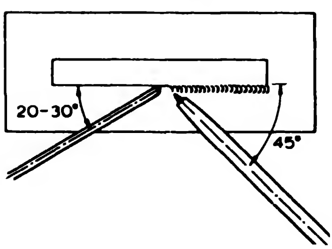
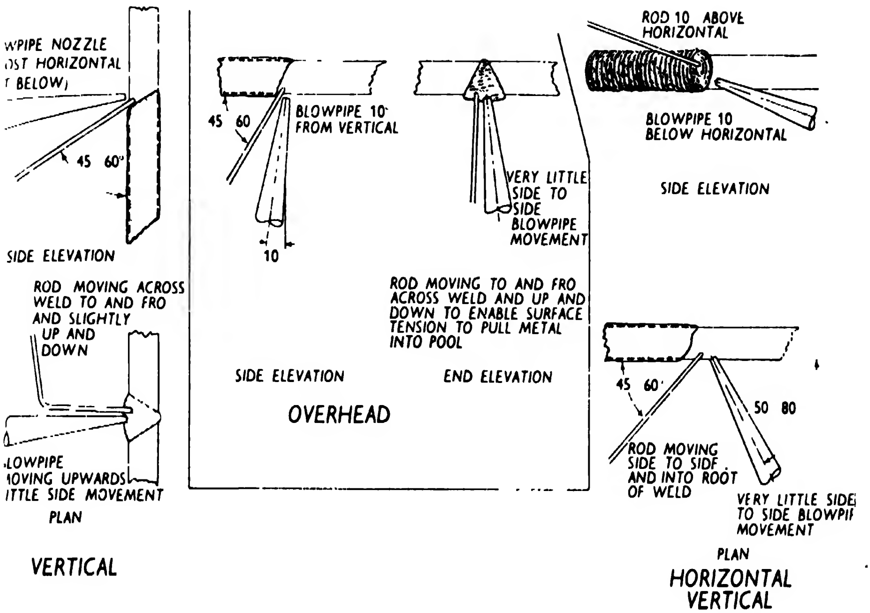


Fig. 13.21. All-position rightward welding



Steel filler rods for oxy-acetylene welding

Rod type	Composition % C	Si	Mn	Ni	Cr	Application
Mild steel (copper coated)	0.1	-	0.6	0.25		General utility low-carbon-steel rod for low and mild carbon steel and wrought iron. UTS 386 N/mm² hardness 120 Brinell, melting point 1490 C.
Medium carbon steel (copper coated)	0.25 0.3	0.3 0.5	1.3 1.6	0.25	0.25	For medium carbon steels, high strength with toughness, UTS 552 N/mm², hardness 150 Brinell, melting point 1400 C
Pipe-welding steel	0.1 0.2 Plus Al, Ti, Zr as deoxidizers up to 0.15% max	0.1 0.35	1.0 1.6			Low carbon steel for high-strength welds in steel pipes. UTS 492 N/mm², hardness 145 Brinell, melting point 1450 .

Note. Phosphorus and sulphur 0.04% max. for all types.

Cast iron welding

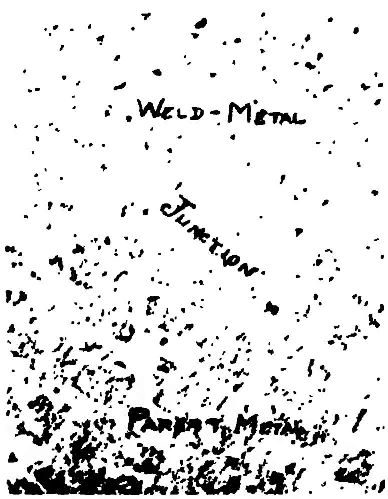
Cast iron, because of its brittleness, presents a different problem in welding from steel. We may consider three types – grey, white and malleable.

The grey cast iron is softer and tougher than the white, which is hard and brittle. The good mechanical properties of grey cast iron are due to the presence of particles of free carbon or graphite, which separate out during slow cooling. When the cooling is rapid, it is impossible for the cementite (iron carbide) to decompose into ferrite and graphite; hence the structure consists of masses of cementite embedded in pearlite, this giving the white variety of cast iron with its hardness and brittleness.

The other constituents of cast iron are silicon, sulphur, manganese and phosphorus. Silicon is very important, because it helps to increase the formation of graphite, and this helps to soften the cast iron. Manganese makes the casting harder and stronger. It has a great affinity for sulphur and, by combining with it, prevents the formation of iron sulphide, which makes the metal hard and brittle. Phosphorus reduces the melting point and increases the fluidity. If present in a greater proportion than 1% it tends to increase the brittleness. Sulphur tends to prevent the formation of graphite and should generally not exceed 0.1%. It may be added to enable the outer layers to have a hard surface (chill casting), while the body of the casting is still kept in the grey state.

The aim of the welder should be always, therefore, to form grey cast iron in the weld (Fig. 13.22).

Fig. 13.22. Oxy-acetylene fusion weld in cast iron × 100.

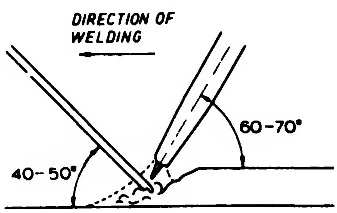


Preparation. The edges are V'd out to 90° on one side only up to 10 mm thickness and from both sides for greater thickness. Pre-heating is essential, because not only does it prevent cracking due to expansion and contraction, but by enabling the weld to cool down slowly, it causes grey cast iron to be formed instead of the hard white unmachinable deposit which would result if the weld cooled off rapidly. Pre-heating may be done by blowpipe, forge or furnace, according to the size of the casting.

Blowpipe, flame, flux and rod. The neutral flame is used, care being taken that there is not the slightest trace of excess oxygen which would cause a weak weld through oxidation, and that the metal is not overheated. The inner cone should be about 3–4 mm away from the molten metal. If it touches the molten metal, hard spots will result. The flux (of alkaline borates) should be of good quality to dissolve the oxide and prevent oxidation, and it will cause a coating of slag to form on the surface of the weld, preventing atmospheric oxidation. Ferro-silicon and super-silicon rods, containing a high percentage of silicon, are the most suitable rods to use.

Technique. The welding operation should be performed on the dull red-hot casting with the rod and blowpipe at the angles shown in Fig. 13.23 and done in the leftward manner. The rod is dipped into the flux at intervals, using only enough flux to remove the oxide. It will be noticed that, as the flux is added, the metal flows more easily and looks brighter, and this gives a good indication as to when flux is required. The excessive use of flux causes blowholes and a weak weld. The rod should be pressed down well into the weld, removing a good percentage of the slag and oxide. Very little motion of the blowpipe is required and the rod should not be stirred round continuously, as this means the formation of more slag with more danger of entrapping it in the weld. Cast-iron welds made by beginners often have brittle parts along the edges, due to their not getting under the oxide and floating it to the top.

Fig. 13.23. Cast iron welding



After treatment. The slag and oxide on the surface of the finished weld can be removed by scraping and brushing with a wire brush, but the weld should not be hammered. The casting is then allowed to cool off very slowly, either in the furnace or fire, or if it has been pre-heated with the flame, it can be put in a heap of lime, ashes or coke, to cool. Rapid cooling will result in a hard weld with possibly cracking or distortion.

Malleable cast iron welding

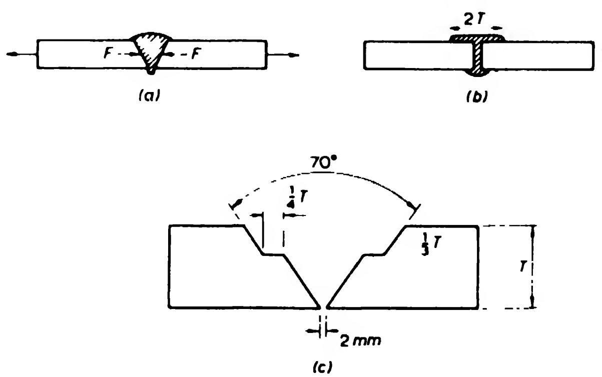
This is unsuitable for welding with cast-iron rods because of its structure. If attempted it invariably results in hard, brittle welds having no strength. The best method of welding is with the use of bronze rods, and is described below.

Braze welding and bronze welding

Braze welding is the general term applied to the process in which the metal filler wire or strip has a lower melting point than that of the parent metal, using a technique similar to that used in fusion welding, except that the parent metal is not melted nor is capillary action involved as in brazing. When the filler metal is made of a copper-rich alloy the process is referred to as bronze welding.

By the use of bronze filler wires such as those given in the table on p.632, a sound weld can be made in steel, wrought iron, cast iron and copper and between dissimilar metals such as steel and copper, at a lower temperature than that usually employed in fusion welding. The bronze filler metal, which has a lower melting point than the parent metal, is melted at the joint so as to flow and 'wet' the surfaces of the joint to form a sound

Fig. 13.24. When specimen (*a*) is subjected to a tensile pull as shown the faces *F* of the joint are partly in shear (*c*) 'Shear V' preparation



bond without fusion of the parent metal. There is less thermal disturbance than with fusion welding due to the lower temperatures involved and the process is simple and relatively cheap to perform. Unlike capillary brazing (see pp. 659–61) the strength of the joint is not solely dependent upon the areas of the surfaces involved in the joint but rather upon the tensile strength of the filler metal. A bronze weld has relatively great strength in shear, and joints are often designed to make use of this (Fig. 13.24*a*, *b* and *c*).

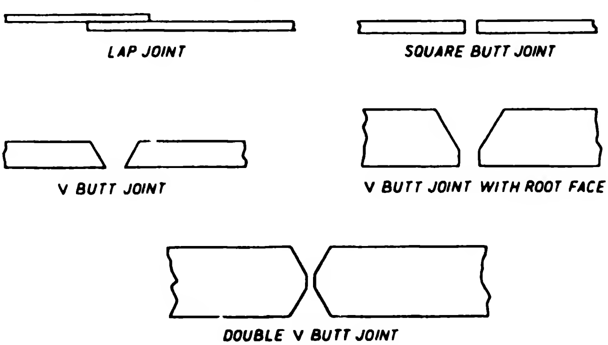
The final strength of the welded joint depends upon the bond between filler metal and parent metal so that thorough cleanliness of the joints and immediate surroundings is essential to ensure that the molten filler metal should flow over the areas and 'wet' them completely without excessive penetration of the parent metal, and there should be freedom from porosity. Care, therefore, should be taken to avoid excessive overheating. Figs. 13.25 and 13.26 show various joint designs for plate and tube.

If bronze filler wires are used on alloys such as brasses and bronzes the melting points of wire and parent metal are so nearly equal that the result is a fusion weld.

General method of preparation for bronze welding. All impurities such as scale, oxide, grease, etc., should be removed, as these would prevent the bronze wetting the parent metal. The metal should be well cleaned on both upper and lower faces for at least 6 mm on each side of the joint, so that the bronze can overlap the sides of the joint, running through and under on the lower face.

Bronze welding is unlike brazing in that the heat must be kept as local as possible by using a small flame and welding quickly. The bronze must flow in front of the flame for a short distance only, wetting the surface, and by having sufficient control over the molten bronze, welding may be done in

Fig. 13.25. Typical joint designs for bronze welding (sheet and plate)



the overhead position. Too much heat prevents satisfactory wetting. We will now consider the bronze welding of special metals using a flux of a mixture of alkaline fluoride and borax, but bronze filler rods are also supplied flux-coated.

Cast iron

Bevel the edges to a 90° V, round off the sharp edges of the V, and clean the casting well. Pre-heating may be dispensed with unless the casting is of complicated shape, and the welding may often be done without dismantling the work. If pre-heating is necessary it should be heated to

British Standards designations, compositions and recommended usage of filler alloys for bronze welding

Alloy designation BS 1453	BS 1845 (Group CZ)	Composition % (by weight) Deleterious impurities, e.g. Al and Pb, are each restricted to 0.3% max		Recommended for usage on	Approx melting point (°C)	Applications
C2	CZ6	Cu 57.00 Si 0.20 Zn balance Sn optional	to 63.00 to 0.50 to 0.50 max	Copper Mild steel	875–895	A silicon-bronze used for copper sheet and tube mild steel and line production applications
C4	CZ7	Cu 57.00 Si 0.15 Mn 0.05 Fe 0.10 Zn balance Sn optional	to 63.00 to 0.30 to 0.25 to 0.50 to 0.50 max	Copper Cast iron Wrought iron	870–900	Similar to C2 (CZ6)
C5	CZ8	Cu 45.00 Si 0.15 Ni 8.00 Zn balance Sn optional Mn optional Fe optional	to 53.00 to 0.50 to 11.00 to 0.50 max to 0.50 max to 0.50 max	Mild steel Cast iron Wrought iron	970–980	A nickel-bronze for bronze welding steel and malleable iron, building up worn surfaces and welding Cu–Zn–Ni alloys of similar composition
C6		Cu 41.00 Si 0.20 Ni 14.00 Zn balance Sn optional Mn optional Fe optional	to 45.00 to 0.50 to 16.00 to 1.00 max to 0.20 max to 0.30 max.	Cast iron Wrought iron	–	Similar to C5 (CZ8)

450°C, and on completion cooling should be as slow as possible as in the fusion welding of cast iron (Fig. 13.27).

Blowpipe, flame and rod. The blowpipe nozzle may be about two sizes smaller than for the same thickness steel plate, and the flame is adjusted so as to give a slight excess of oxygen. If a second deposit is to be run over the first, the flame is adjusted to a more oxidizing condition still for the subsequent runs, the inner cone being usually only about $\frac{3}{4}$ of its neutral length. The best flame condition can easily be found by trial. Suitable filler

Fig. 13.26. Typical joint designs for bronze welding (tube)

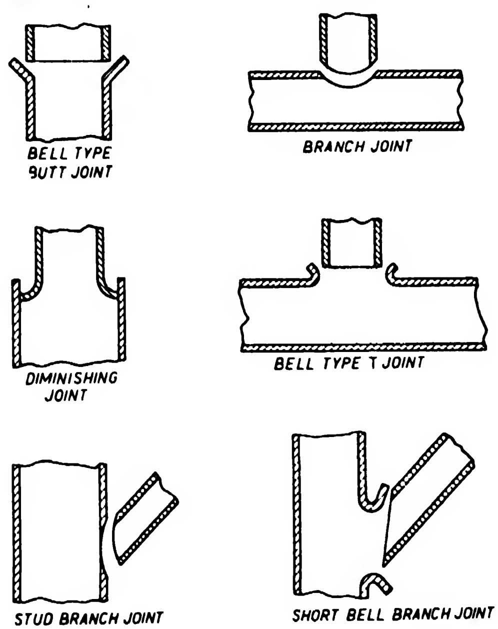
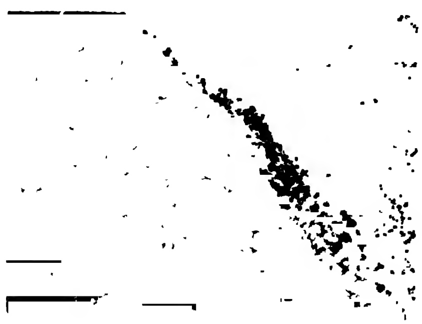


Fig. 13.27. Bronze weld in cast iron



alloys are given in the table, those containing nickel giving greater strength, the bronze flux being of the borax type.

Technique. The leftward method is used with the rod and blowpipe held as in Fig. 13.28, the inner cone being held well away from the molten metal. The rod is wiped on the edges of the cast iron and the bronze wets the surface. It is sometimes advisable to tilt the work so that the welding is done uphill, as shown in Fig. 13.28. This gives better control. Do not get the work too hot.

Vertical bronze welding of cast iron can be done by the two-operator method, and often results in saving of time, gas and rods and reduces the risk of cracking and distortion.

The edges are prepared with a double 90° V and thoroughly cleaned for 12 mm on each side of the edges. The blowpipes are held at the angle shown in Fig. 13.29*a*. Blowpipe and rod are given a side to side motion, as indicated in Fig. 13.29*b* as the weld proceeds upwards, so as to tin the surfaces.

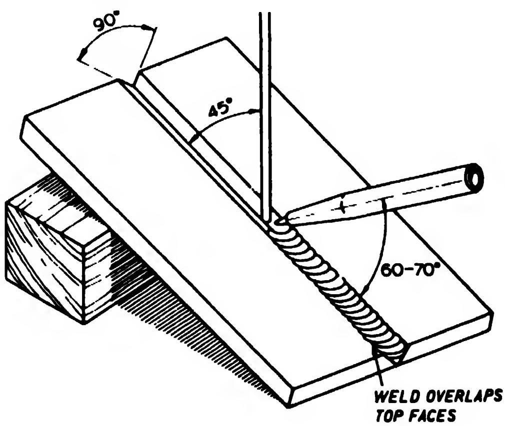
Malleable cast iron

The bronze welding of malleable castings may be stated to be the only way to ensure any degree of success in welding them. Both types (blackheart and whiteheart) can be welded satisfactorily in this way, since the heat of the process does not materially alter the structure. The method is the same as for cast iron, using nickel bronze rods (C5) and a borax-type flux.

Steel

In cases where excessive distortion must be avoided, or where thin sections are to be joined to thick ones, the bronze welding of steel is often

Fig. 13.28. Bronze welding cast iron.



used, the technique being similar to that for cast iron, except, of course, that no pre-heating is necessary.

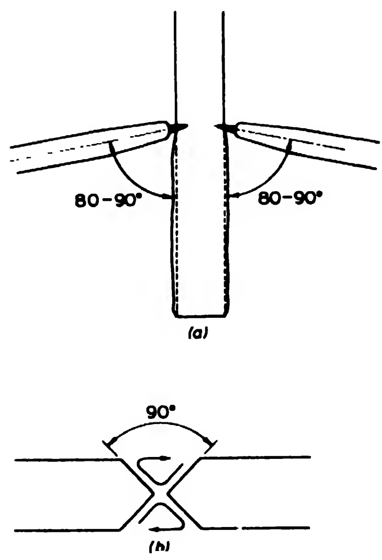
Galvanized iron

This can be easily bronze welded, and will result in a strong corrosion-resisting joint, with no damage to the zinc coating. If fusion welding is used, the heat of the process would of course burn the zinc (or galvanizing) off the joint and the joint would then not resist corrosion.

Preparation, flame and rod. For galvanized sheet welding, the edges of the joint are tack welded or held in a jig and smeared with a silver–copper flux. Thicker plates and galvanized pipes are bevelled 60–80° and tacked to position them. The smallest possible nozzle should be used (for the sheet thickness) and the flame adjusted to be slightly oxidizing. Suitable filler alloys are given in the table (p. 632) as for steel.

Technique. No side to side motion of the blowpipes is given, the flame being directed on to the rod, so as to avoid overheating the parent sheet. The rod is stroked on the edges of the joint so as to wet them. Excessive flux *must* be washed off with hot water.

Fig. 13.29. (*a*) Two-operator vertical bronze welding of cast iron (*b*) Showing motion of pipe and rod



Copper

Tough pitch copper can be readily bronze welded owing to the much lower temperature of the process compared with fusion welding (Fig. 13.30).

Preparation, flame and rod. Preparation is similar to that for cast iron. Copper tubes can be bell mouthed (Fig. 13.31). Special joints are available for multiple branches. The blowpipe nozzle should be small and will depend on the size of the work or the diameter of the pipe to be welded, and should be chosen so that the bronze flows freely but no overheating occurs. The flame should be slightly oxidizing, and if a second run is made, it should be adjusted slightly to be more oxidizing still (inner cone about $\frac{3}{4}$ of its normal neutral length). Suitable filler alloys are given in the table (p. 632) and are used with a bronze-base flux.

Fig. 13.30. Bronze weld in copper × 250

Technique. The method is similar to that for cast iron, and the final difference between the bronze-welded and brazed joint is that the former has the usual wavy appearance of the oxy-acetylene weld, while the latter has a smooth appearance, due to the larger area over which the heat was applied. The bronze joint is, of course, much stronger than the brazed one.

Brasses and zinc-containing bronzes

Since the filler rod now melts at approximately the same temperature as the parent metal, this may now be called fusion welding. When these alloys are heated to melting point, the zinc is oxidized, with copious evolution of fumes of zinc oxide, and if this continued, the weld would be full of bubble holes and weak (Fig. 13.32). This can be prevented by using an oxidizing flame, so as to form a layer of zinc oxide over the molten metal, and thus prevent further formation of zinc oxide and vaporization.

Preparation. The edges of the faces of the joint are cleaned and prepared as usual, sheets above 3.2 mm thickness being V'd to 90°. Flux can be applied by making it into a paste, or by dipping the rod into it in the usual manner, or a flux-coated rod can be used.

Flame and rod. Suitable filler alloys are given in the table (p. 632), while a brass rod is used for brass welding, the colour of the weld then being similar to that of the parent metal. Owing to the greater heat conductivity, a larger size jet is required than for the same thickness of steel plate. The flame is adjusted to be oxidizing, as for bronze welding cast iron, and the exact flame condition is best found by trial as follows. A small test piece of the brass or bronze to be welded is heated with a neutral flame and gives off copious fumes of zinc oxide when molten. The acetylene is now cut down until no more fumes are given off. If any blowholes are seen in the metal on solidifying the acetylene should be reduced slightly further. The inner cone will now be about half its normal neutral length. Too

Fig. 13.31

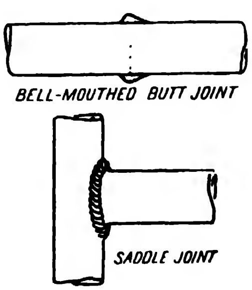
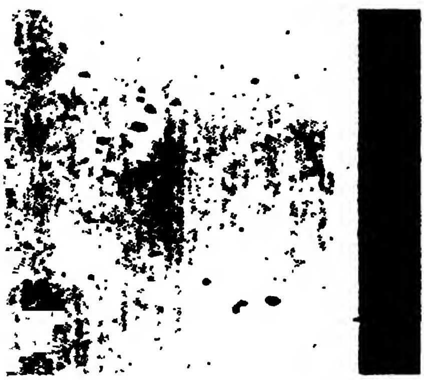


Fig. 13.32. (*a*) Unsatisfactory brass weld made with neutral flame, Unetched × 2.5. (*b*) Brass weld made with insufficient excess of oxygen. Unetched. (*c*) Correct brass weld made with adequate excess of oxygen. Unetched. × 2.5

a



b

much oxygen should be avoided, as it will form a thick layer of zinc oxide over the metal and make the filler rod less fluid.

The weld is formed in the 'as cast' condition, and hammering improves its strength. Where 60/40 brass rods have been used the weld should be hammered while hot, while if 70/30 rods have been used the weld should be hammered cold and finally annealed from dull red heat.

Tin bronze

Tin bronze cannot be welded using an oxidizing flame. Special rods and fluxes are available, however, with which good welds can be made. Urgent repairs may be safely carried out using a *neutral* flame and a silicon–bronze rod with borax-type flux.

Gilding metal

For the weld to be satisfactory on completion, the weld metal must have the same colour as the parent metal. Special rods of various compositions are available, so that the colours will 'match'.

Aluminium bronze

Aluminium bronze can be welded using a filler rod of approximately 90% copper, 10% aluminium (C13, BS 2901 Pt 3), melting point 1040 °C, a rod also suitable for welding copper, manganese bronze and alloy steels where resistance to shock, fatigue and sea-water corrosion is required. The aluminium bronze flux (melting point 940 °C) can be mixed with water to form a paste if required.

Preparation. The edges of the joint should be thoroughly cleaned by filing or wire brushing to remove the oxide film which is difficult to dissolve.

Up to 4.8 mm thickness no preparation is required – just a butt joint with gap. Above 4.8 mm the usual V preparation is required and a double V above 16 mm thick. Sheets should not be clamped for welding, as this tends to cause the weld to crack, they must be allowed to contract freely on cooling, and it is advisable to weld a seam continuously and not make starts in various places.

Flame and rod. A neutral flame is usually used – any excess of acetylene tends to produce hydrogen with porosity of the weld, while excess oxygen causes oxidation. Flame size should be carefully chosen according to the thickness of the plate – too small a flame causes the weld metal to solidify too quickly while there is a danger of burning through with too large a flame.

The filler rod should be a little thicker (0.8 mm) than the sheet to be welded to avoid overheating, and it should be added quickly to give complete penetration without deep fusion.

Technique. The leftward method is used with a steep blowpipe angle (80°) to start the weld, this being reduced to 60–70° as welding progresses. The parent metal should be well pre-heated prior to starting welding and during welding a large area should be kept hot to avoid cracks. The rod should be used with a scraping motion to clean the molten pool and remove any entrapped gas.

In welding the single-constituent (or α phase) aluminium bronze, i.e. 5–7% Al, 93% Cu, the weld metal should be deposited in a single run or at most two runs to avoid intergranular cracks. Since the metal is hot short in the range 500–700°C it should cool quickly through the range, and should not be peened. Cold peening is sometimes an advantage. The two-constituent (α and β) or duplex aluminium bronzes contain 10% aluminium. They have a wide application, are not as prone to porosity, and are easier to weld than the 7% Al type, and also their hot short range is smaller.

After treatment. Stresses can be relieved by heat treating at low temperature, and any required heat treatment can be carried out as required after welding.

Copper welding

Tough pitch copper (that containing copper oxide) is difficult to weld, and so much depends on the operator's skill that it is advisable to specify deoxidized copper for all work in which welding is to be used as the method of jointing. Welds made on tough pitch copper often crack along the edge of the weld if they are bent (Fig. 13.33*a*), showing that the weld is unsound due to the presence of oxide, often along the lines of fusion. A *good* copper weld (Fig. 13.33*b*), on the other hand, can be bent through 180° without cracking and can be hammered and twisted without breaking. This type of copper weld is strong and sound, free from corrosion effects, and is eminently satisfactory as a method of jointing.

Preparation. The surfaces are thoroughly cleaned and the edges are prepared according to the thickness, as shown in Fig. 13.34. In flanging thin sheet the height of the flange is about twice the plate thickness and the flanges are bent at right angles. Copper has a high coefficient of expansion, and it is necessary therefore to set the plates diverging at the rate of 3–4 mm

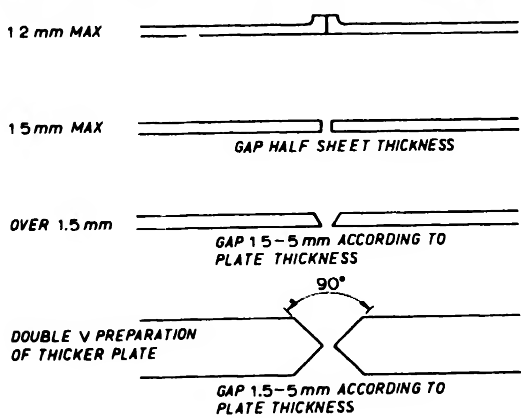
per 100 mm run, because they come together so much on being welded. Since copper is weak at high temperatures, the weld should be well supported if possible and an asbestos sheet between the weld and the backing strip of steel prevents loss of heat.

Tacking to preserve alignment is not advised owing to the weakness of the copper tacks when hot. When welding long seams, tapered spacing clamps or jigs should be used to ensure correct spacing of the joint, care

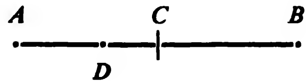
Fig. 13.33. (*a*) Poor copper weld Crack developed when bent. (*b*) Oxy-acetylene weld in deoxidized copper. × 100.

a b

Fig. 13.34. Preparation of copper plates for welding.



being taken that these do not put sufficient pressure on the edges to indent them when hot. A very satisfactory method of procedure is to place a clamp *C* at the centre of the seam and commence welding at a point say about one-third along the seam.



Welding is performed from *D* to *B* and then from *D* to *A*.

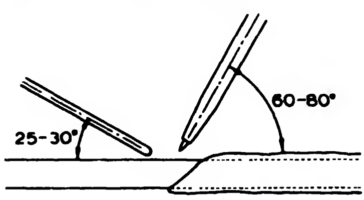
Because of the high conductivity of copper it is essential to pre-heat the surface, so as to avoid the heat being taken from the weld too rapidly. If the surface is large or the metal thick, two blowpipes must be used, one being used for pre-heating. When welding pipes they may be flanged or plain butt welded, while T joints can be made as saddles.

Blowpipe, flame and rod. A larger nozzle than for the same thickness of steel should be used and the flame adjusted to be neutral or very slightly carbonizing. Too much oxygen will cause the formation of copper oxide and the weld will be brittle. Too much acetylene will cause steam to form, giving a porous weld, therefore close the acetylene valve until the white feathery plume has almost disappeared. The welding rod should be of the deoxidized type, and many alloy rods, containing deoxidizers and other elements such as silver to increase the fluidity, are now available and give excellent results.

The weld may be made without flux, or a flux of the borax type used. Proprietary fluxes containing additional chemicals greatly help the welding operation and make it easier.

Technique. The blowpipe is held at a fairly steep angle, as shown in Fig. 13.35, to conserve the heat as much as possible. Great care must be taken to keep the tip of the inner cone 6–9 mm away from the molten metal, since the weld is then in an envelope of reducing gases, which prevent oxidation. The weld proceeds in the leftward manner, with a slight sideways motion of the blowpipe. Avoid agitating the molten metal, and do not remove the rod from the flame but keep it in the molten pool. Copper may

Fig. 13.35. Copper welding.



also be welded by the rightward method, which may be used when the filler rod is not particularly fluid. The technique is similar to that for rightward welding of mild steel, with the flame adjusted as for leftward welding of copper.

Welding can also be performed in the vertical position by either single- or double-operator method, the latter giving increased welding speed.

After treatment. Light peening, performed while the weld is still hot, increases the strength of the weld. The effect of cold hammering is to consolidate the metal, but whether or not it should be done depends on the type of weld and in general is not advised. Annealing, if required on small articles, can be carried out by heating to 600–650° C.

Aluminium welding

The welding of aluminium, either pure or alloyed, presents no difficulty (Fig. 13.36) provided the operator understands the problems which must be overcome and the technique employed.

The oxide of aluminium (alumina Al_2O_3), which is always present as a surface film and which is formed when aluminium is heated, has a very high melting point, much higher than that of aluminium, and if it is not removed it would become distributed throughout the weld, resulting in weakness and brittleness. A good flux, melting point 570° C, is necessary to dissolve this oxide and to prevent its formation.

Fig. 13.36. Oxy-acetylene weld in aluminium. × 45.

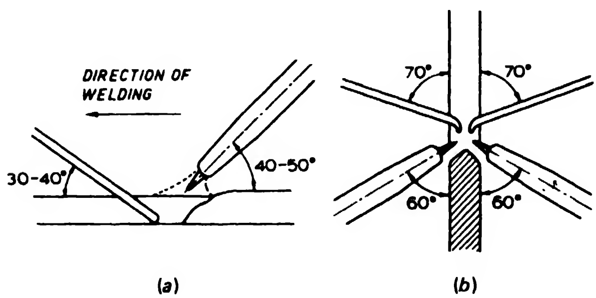
Aluminium and its alloys

Preparation. The work should be cleaned of grease and brushed with a wire brush. Sheets below 1 mm thickness can be turned up at right angles (as for mild steel) and the weld made without a filler rod. Over 3.2 mm thick the edges should have a 90° V and over 6 mm thick a double 90° V. Tubes may be bevelled if thick or simply butted with a gap between them. It is advisable always to support the work with backing strips of asbestos or other material, to prevent collapse when welding. Aluminium, when near its melting point, is extremely weak, and much trouble can be avoided by seeing that no collapsing can occur during the welding operation.

Blowpipe, flame, flux and rod. The flame is adjusted to have a very slight excess of acetylene and then adjusted to neutral, and the rod of pure aluminium or 5% silicon aluminium alloy should be a little thicker than the section to be welded. A good aluminium flux must be used and should be applied to the rod as a varnish coat, by heating the end of the rod, dipping it in the flux and letting the tuft, which adheres to the rod, run over the surface for about 150 mm of its length. This ensures an even supply. Too much flux is detrimental to the weld.

Technique. The angles of the blowpipe and rod are shown in Fig. 13.37 (a slightly larger angle between the blowpipe and rod than for mild steel), and the welding proceeds in the leftward manner, keeping the inner cone well above the molten pool. The work may be tacked at about 150 mm intervals to preserve alignment, or else due allowance made for the joint coming in as welded, like mild steel. As the weld progresses and the metal becomes

Fig. 13.37. (*a*) Aluminium flat welding. Rightward technique may also be employed using approximately the same angles of blowpipe and rod. (*b*) Aluminium welding by the double-operator method



hotter, the rate of welding increases, and it is usual to reduce the angle between blowpipe and weld somewhat to prevent melting a hole in the weld. Learners are afraid of applying sufficient heat to the joint as a rule, because they find it difficult to tell exactly when the metal is molten, since it does not change colour and is not very fluid. When they do apply enough heat, owing to the above difficulty, the blowpipe is played on one spot for too long a period and a hole is the result.

If the rightward technique is used the blowpipe angle is 45° and the rod angle 30–40°. Distortion may be reduced when welding sheets, and the flame anneals the deposited metal.

The two-operator vertical method may be employed (as for cast iron) on sheets above 6 mm thickness, the angle of the blowpipes being 50–60° and the rods 70–80°. This method gives a great increase in welding speed (Fig. 13.37).

After treatment. All the corrosive flux must be removed first by washing and scrubbing in hot soapy water. This can be followed by dipping the article in a 5% nitric acid solution followed by a washing again in hot water.

Where it is not possible to get at the parts for scrubbing, such as in tanks, etc., the following method of removal is suitable. Great care, however, should be taken when using the hydrofluoric acid as it is dangerous, and rubber gloves should be worn, together with a face mask.

A solution is made up as follows in a heavy duty polythene container.

Nitric acid   100 g to 1 litre water.
Hydrofluoric acid – 6 g to 1 litre water.

The nitric acid is added to the water first, followed by the hydrofluoric acid.

Articles immersed in this solution for about ten minutes will have all the flux removed from them, and will have a uniformly etched surface. They should then be rinsed in cold water followed by a hot rinse, the time of the latter not exceeding three minutes, otherwise staining may occur.

Hammering of the completed weld greatly improves and consolidates the structure of the weld metal, and increases its strength, since the deposited metal is originally in the 'as cast' condition and is coarse grained and weak. Annealing may also be performed if required.

Aluminium alloy castings and sheets

The process for the welding of castings is very similar to that for the welding of sheet aluminium. See pp. 131–2 for explanation of alloy coding letters.

Preparation. The work is prepared by V'ing if the section is thicker than 3 mm, and the joint is thoroughly cleaned of grease and impurities. Castings such as aluminium crank-cases are usually greasy and oily (if they have been in service), the oil saturating into any crack or break which may have occurred. If the work is not to be pre-heated, this oil *must* be removed. It may be washed first in petrol, then in a 10% caustic soda solution, and this followed by a 10% nitric acid or sulphuric acid solution. A final washing in hot water should result in a clean casting. In normal cases in which pre-heating is to be done, filing and a wire brush will produce a clean enough joint, since the pre-heating will burn off the remainder.

Aluminium alloys. Recommended filler rods

Alloys	Composition % (remainder aluminium)	Filler rod (old designation in brackets)
Casting alloys BS 1490		
LM2	0.7–2.5 Cu, 9–11.5 Si	4047A, 10–12% Si (NG2)
LM4	2–4 Cu, 4–6 Si	4047A or 4043A, 4.5–6% Si (NG2 or NG21)
LM5	3–6 Mg	5356, 4.6–5.5 Mg (NG6)
LM6	10–13 Si, 0.5 Mn	4043, 4.5–6.0 Si (NG21)
LM9	10–13 Si, 0.3–0.7 Mn	4043 or 4047 (NG21 or NG2)
LM18	4.5–6 Si	4043 (NG21)
LM20	10–13 Si, 0.4 Cu	4047 (NG2)
Wrought alloys BS 1470–1477		
1080A	99.8 Al	1080A (G1B)
1050A	99.5 Al	1080A (G1C)
3103 (N3)	1–1.5 Mn	3103 (NG3)
6063 (H9)	0.4–0.9 Mg, 0.3–0.7 Mn	4043 or 5056A (NG21 or NG6)
061 (H20)	0.15 C 0.4 Cu, 0.8–1.2 Mg, 0.4–0.8 Si, 0.2–0.8 Mn, 0.15–0.35 Cr	4043 or 5056A (NG21 or NG6)
6082 (H30)	0.5–1.2 Mg, 0.7–1.3 Si, 0.4–1.0 Mn	4043 or 5056A (NG21 or NG6)

If the casting is large or complicated, pre-heating should be done as for cast iron.* In any case it is advantageous to heat the work well with the blowpipe flame before commencing the weld.

* Large complicated castings can be pre-heated to about 400 °C, smaller castings to 300–350 °C and small castings to 250–300 °C. No visible change in the appearance of the aluminium occurs at these temperatures.

Blowpipe, flame, rod and flux. The blowpipe is adjusted as for pure aluminium and a similar flame used. The welding rod should preferably be of the same composition as the alloy being welded (see table on p. 632) but for general use a 5% silicon–aluminium rod is very satisfactory. This type of rod has strength, ductility, low shrinkage, and is reasonably fluid. A 10% silicon–aluminium rod is used for high silicon castings, while 5% copper–aluminium rods are used for the alloys containing copper, such as Y alloy, and are very useful in automobile and aircraft industries. The deposit from this type of rod is harder than from the other types.

When welding the Al–Mg alloys the oxide film consists of both aluminium and magnesium oxide making the fluxing more difficult so that as the magnesium proportion increases welding may become more difficult. Alloys containing more than $2\frac{1}{2}\%$ Mg, e.g. 5154A (N5) and 5183 (N8) are difficult to weld and require considerable experience as do the high strength alloys 6061 (H15) and 6082 (H30). The inert gas arc processes are to be preferred for welding these alloys.

Since there is also a loss of Mg in the welding process note that the filler rod recommended has a greater Mg content than the parent plate. The flux used is similar to that for pure aluminium and its removal must be carried out in the same way.

Technique. The welding is carried out as for aluminium sheet, and the cooling of the casting after welding must be gradual.*

After-treatment. After welding, the metal is in the 'as cast' condition and is weaker than the surrounding areas of parent metal, and the structure of the deposited metal may be improved by hammering. The area near the welded zone, however, is annealed during the welding process and failure thus often tends to occur in the area alongside the weld, and not in the weld itself. In the case of heat-treatable alloys, the welded zone can be given back much of its strength by first lightly hammering the weld itself and then heat-treating the whole of the work.

For this to be quite successful it is essential that the weld should be of the same composition as the parent metal. If oxidation has occurred, however, this will result in a weld metal whose structure will differ from that of the parent metal and the weld will not respond to heat treatment. Since many of this type of alloy are 'hot short', cracking may occur as a result of the welding process.

When repairing cracked castings, any impurities which appear in the molten pool should be floated to the top, using excess flux if necessary

If sheets are anodized, the welding disturbs the area and changes its appearance. Avoidance of overheating, localizing the heat as much as possible, and hammering, will reduce this disturbance to a minimum, but heat treatment will make the weld most inconspicuous.

Welding of nickel and nickel alloys

The alloys include MONEL® (nickel–copper) and INCONEL® (nickel–chromium) alloys and modifications of these constituents to give variations in properties.

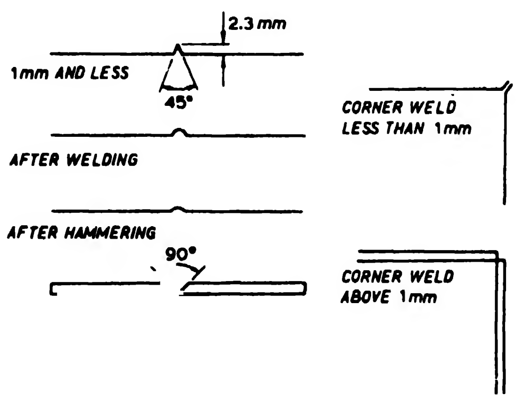
Oxy-acetylene welding is used only for welding Nickel 200 alloy, certain MONEL® alloys, INCO® and INCONEL® alloys. Welding of nickel–chromium–cobalt alloys (NIMONIC® alloy) is not usually performed. (Consult the manufacturers for up to date details.)

Preparation. Sheets of thinner than 1 mm can be bent up through an angle of about 75°, as shown in Fig. 13.38, and the edges melted together. The ridge formed by welding can then be hammered flat. Sheets thicker than 1 mm are bevelled with the usual 90° V and butted together. For corner welds on sheet less than 1 mm the corners are flanged as shown, while for thicker plate the weld is treated as an open corner joint (see Fig. 13.38). Castings should be treated as for cast iron.

In tube welding, preparation should be an 80° V with no root gap.

Blowpipe, flame, flux and rod, High-purity acetylene as supplied from DA cylinders is required, and in general the blowpipe nozzle size is the same as that for the same thickness mild steel. For nickel 200 a size larger can be used. No flux is required for nickel 200 and for Incoloy DS the use of flux is

Fig. 13.38. Preparation of plates.



optional and special fluxes are available for the other alloys. Flux containing boron should not be used with alloys containing chromium as it tends to cause hot cracking in the weld. The joint is tacked in position without flux. The flux is made into a thin paste and painted onto both sides of the joint and the filler rod and allowed to dry before welding. Fused flux remaining should be removed by wire brushing and unfused flux with hot water. Flux remaining (after welding the nickel chromium alloys) can be removed by treatment with a solution of equal parts of nitric acid and water for 15–30 minutes followed by washing with water. Flux removal is important when high-temperature applications are involved, as the flux may react with the metal.

Technique. Leftward technique is used. Weaving and puddling of the molten pool should be avoided as agitation of the pool causes porosity due to the absorption of gases by the high-nickel alloys, and the filler rod should be kept within the protective envelope of the flame to prevent oxidation. Keep the flame tip above the pool but for MONEL® alloy K500 let it just touch the pool. Nickel 200 melts sluggishly. INCONEL® alloy 600, NIMONIC® alloy 75 and the BRIGHTRAY® alloys are more fluid while MONEL® alloy 400 and INCOLOY® DS alloy flow easily. A slightly carburizing soft flame (excess acetylene) should be used for the nickel and nickel–copper alloys, whilst for the chromium-containing alloys the flame should be a little more carburizing.

There are no pronounced ripples on the weld surface. They should be smooth without roughness, burning or signs or porosity.

Examples of filler metals

Material	
Nickel alloys 200, 201	Nickel filler metal 61
MONEL® alloys 400, R405, K500	MONEL® filler metal 60
INCONEL® alloy 600	INCONEL® filler metal 62
INCONEL® alloys 600, 601 INCOLOY® alloys 800, 800HT	INCONEL® filler metal 82
INCO® alloy 330	
INCOLOY® DS	N/C (nickel–chromium) filler metal

When welding tube with 80° feather edge preparation and no root gap, the first run is made with no filler rod, the edges being well fused together to give an even penetration bead, followed by filler runs. If the work is rotatable, welding in the two o'clock position gives good metal control. If the joint is fixed, vertical runs should be made first downwards followed by a run upwards.

Nickel clad steel*

This steel is produced by the hot rolling of pure nickel sheet on to steel plate, the two surfaces uniting to form a permanent bond. It gives a material having the advantage of nickel, but at much less cost than the solid nickel plate. It can be successfully welded by the oxy-acetylene process.

Preparation. The bevelled 90° butt joint is the best type. For fillet welds it is usual to remove (by grinding) the nickel cladding on the one side of the joint, as shown in Fig. 13.39, so as to ensure a good bond of steel to steel.

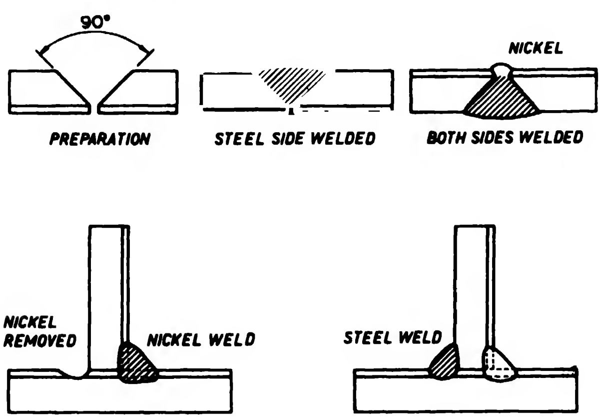
Technique. The weld is made on the steel side first, using a mild steel rod and the same technique as for mild steel. The nickel side is then welded, using a nickel rod and a slightly reducing flame as for welding monel and nickel. The penetration should be such that the nickel penetrates and welds itself into the steel weld.

Stainless steels

Stainless steels of the martensitic and austenitic class can be welded by the oxy-acetylene process.

Preparation. Thin gauges may be flanged at 90° as for mild steel sheet and the edges fused together. Thicker sections are prepared with the usual 90° V and the surfaces cleaned of all impurities. The coefficient of expansion of the 18/8 austenitic steels is about 50% greater than that of mild steel, and consequently the sheets should be set diverging much more than for mild

Fig. 13.39. Double fillet weld. Nickel clad steel.



* Also stainless clad steel

steel to allow for them coming together during welding. An alternative method is to tack the weld at both ends first, and then for sheets thinner than 1 mm tack at 25 mm intervals, while for thicker sheets the tacks can be at 50 mm intervals. Cooling clamps are advised for the austenitic steels. The thermal conductivity is less than for mild steel, and thus the heat remains more localized. Unless care is taken, therefore, the beginner tends to penetrate the sheet when welding thin gauges.

Flame. The flame should be very slightly carburizing (excess acetylene), there being the smallest trace of a white plume around the inner cone. The flame should be checked from time to time to make sure that it is in this condition, since any excess oxygen is fatal to a good weld, producing porosity, while too great an excess of acetylene causes a brittle weld.

Rod and flux. The welding rod must be of the same composition as the steel being welded, the two types normally used being the 18/8 class, and one having a higher nickel and chromium content and suitable for welding steels up to a 25/12 chrome–nickel content. Since there is considerable variety in the amounts of the various elements added to stainless steels to improve their physical properties, such as molybdenum and tungsten in addition to titanium or niobium, it is essential that the analysis of the parent metal be known so that a suitable rod can be chosen. The steel makers and electrode makers will always co-operate in this matter. The rod should be of the same gauge or slightly thicker than the sheet being welded. No flux is necessary, but if difficulty is experienced with some steels in penetration, a special flux prepared for these steels should be used, and can be applied as a paste mixed with water.

Technique. Welding is performed in the leftward manner, and the flame is played over a larger area than usual because of the low thermal conductivity. This lessens the risk of melting a hole in the sheet. The tip of the inner cone is kept very close to the surface of the molten pool and the welding performed exactly as for the leftward welding of mild steel. No puddling should be done and the least possible amount of blowpipe motion used.

After treatment. Martensitic stainless steels should be heated to 700 to 800°C and then left to air cool. The non-stabilized steels require heat treatment after welding if they are to encounter corrosive conditions, otherwise no heat treatment is necessary. The weld decay-proof stabilized

steels and those with a very low carbon content require no heat treatment after welding.

The original silver-like surface can be restored to stainless steels which have scaled or oxidized due to heat by immersing in a bath made up as follows: sulphuric acid 8%, hydrochloric acid 6%, nitric acid 1%, water 85%. The temperature should be 65 °C and the steel should be left in for 10 to 15 minutes, and then immersed for 15 minutes or until clean in a bath of 10% nitric acid, 90% water, at 25 °C.

Other baths made up with special proprietary chemicals with trade names will give a brighter surface. These chemicals are obtainable from the makers of the steel.

Stainless iron

The welding of stainless iron results in a brittle region adjacent to the weld. This brittleness cannot be completely removed by heat treatment, and thus the welding of stainless iron cannot be regarded as completely satisfactory. When, however, it has to be welded the welding should be done as for stainless steel, using a rod specially produced for this type of iron.

Hard surfacing and stelliting

Surfaces of intense hardness can be applied to steel, steel alloys, cast iron or monel metal, by means of the oxy-acetylene flame. The surfaces are hard and have intense resistance to wear and corrosion. By depositing a surface on a more ductile metal we have an excellent combination. Metals easily hardfaced are low- and medium-carbon steels, steels above 0.4% C, low-alloy steels, nickel, nickel–copper alloys, chrome-nickel and nobium bearing stainless steels (not titanium bearing nor free machining). Those metals faced with difficulty include cast iron, straight chromium stainless steels, tool and die steels and water-, air- and oil-hardening steels while copper, brass and other low melting point alloys are not suitable for hard surfacing. Hard surfaces may be deposited either on new parts so that they will have increased resistance to wear at reduced cost, or on old parts which may be worn, thus renewing their usefulness. In addition, non-ferrous surfaces, such as bronze or stellite, may be deposited and are described under their respective headings.

The surfaces deposited may be hard and/or wear and corrosion resisting. It is usual in the case of hard surfaces for the metal to be machinable as deposited, but to be capable of being hardened by quenching or by work hardening, e.g. 12/14% Mn (see table of rods available on p. 665).

We may divide the methods as follows:

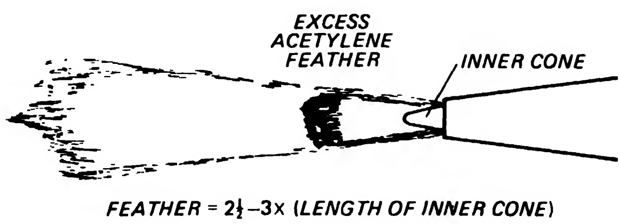
(1) Building up worn parts with a deposit similar to that of the parent metal. This process is very widely used, being cheap and economical, and is used for building up, for example, gear wheels, shafts, key splines, etc.
The technique employed is similar to that for mild steel, using a neutral flame and the leftward method. The deposit should be laid a little at a time and the usual precautions taken for expansion and distortion. Large parts should be pre-heated and allowed to cool out very slowly, and there are no difficulties in the application.

(2) Building up surfaces with rods containing, for example, carbon, manganese, chromium or silicon to give surfaces which have the required degree of hardness or resistance to wear and corrosion. These surfaces differ in composition from that of the parent metal, and as a result the fusion method of depositing cannot be used, since the surface deposit would become alloyed with the base metal and its hardness or wear-resisting properties would be thus greatly reduced.

(3) Hard facing with tungsten carbide. The rods consist of a steel tube containing fused granules of tungsten carbide HV 1800 in a matrix of chromium iron HV 850. Various grades are available with granules of different mesh size. Large granules embedded in the steel surface do not round off as wear takes place, but chip because they are brittle and maintain good serrated cutting edges. Finer mesh granules give a more regular cutting edge so that the mesh of the granules is determined by the working conditions.

Technique. The flame is adjusted to have excess acetylene with the white plume from $2\frac{1}{2}$ to 3 times the length of the inner cone (Fig. 13.40*a*). As the heated surface absorbs carbon, its melting point is reduced and the surface sweats. The rod is melted on to this sweating surface and a sound bond is

Fig. 13.40. (*a*) Hard surfacing flame making the surface sweat



made between deposit and parent metal with the minimum amount of alloying taking place.

This type of deposit, used for its wear-resisting properties, is usually very tough and is practically unmachinable. The surface is therefore usually ground to shape, but in many applications, such as in reinforcing tramway and rail crossings, it is convenient and suitable to hammer the deposit to shape while hot, and thus the deposit requires a minimum amount of grinding. The hammering, in addition, improves the structure.

In the case of the high-carbon deposits, they can be machined or ground to shape and afterwards heat treated to the requisite degree of hardness.

When using tungsten carbide rods the cone of the flame should be played on the rod and pool to allow gases to escape, preventing porosity. Weaving is necessary to give an even distribution of carbide granules in the matrix. Second runs should be applied with the same technique as the first, with no puddling of the first run since this would give dilution of the hard surface with the parent plate.

Another method frequently used to build up a hard surface is to deposit a surface of cast iron in the normal way, using a silicon cast iron rod and flux. Immediately the required depth of deposit has been built up, the part is quenched in oil or water depending on the hardness required.

This results in a hard deposit of white cast iron which can be ground to shape, and which possesses excellent wear-resisting properties. This method is suitable only for parts of relatively simple shape, that will not distort on quenching, such as camshafts, shackle pins, pump parts, etc.

The use of carbon and copper fences in building up and resurfacing results in the deposit being built much nearer to the required shape, reducing time in welding and finishing and also saving material.

When hard surfacing cast iron, the surface will not sweat. In this case the deposit is first laid as a fusion deposit, with a neutral flame, and a second layer is then 'sweated' on to this first layer. In this way the second layer is obtained practically free from any contamination of the base metal.

It will be seen, therefore, that the actual composition of the deposit will depend entirely upon the conditions under which it is required to operate. A table of alloy steel rods and uses is given at the end of this chapter.

Stellite

Stellite alloys of the cobalt–chrome type with carbon were first developed in 1900 in the US and were the first wear-resistant cobalt-based alloys to be used. Later tungsten and/or molybdenum were added. They are hard and have a great resistance to wear and corrosion and there are now

about 20 Stellite alloys available, covering a wide field of resistant surfaces. They can be divided into:

(1) Co–Cr–W–C,

(2) Co–Cr–W/Mo–Ni/Fe–C.

The latter alloys of group (2) have been developed for high-temperature, high-impact wear operations.

The carbon content of the alloys varies from 0.1 % to 3.0 % and over half of them have a carbon content above 1 %. Those with less carbon have a combined carbon plus boron content greater than 1 %. (The cobalt-based alloys are discussed in Chapter 8 on hard facing by MMA.)

Stellite alloys available for use with the oxy-acetylene process with the hardness Rockwell on the C scale and VPH are:

> No. 1 53R, 590VPH; No. 4 47R 480VPH; No. 6 42R, 420VPH; No. 12 48R, 500VPH; No. 20 55R, 620VPH; No. 190 52R, 580VPH; No. 2006 44R, 440VPH; No. 2012 49R, 520VPH.

In general, wear resistance increases as the hardness increases, owing to the dispersal of the hard carbides in the somewhat softer matrix. Stellite alloys preserve their hardness at elevated temperatures dependent upon the W and/or the Mo content. Bare tube rods of granulated tungsten carbide or of a 60/40 percentage of tungsten carbide with either Stellite No. 6 steel tube filled with the tungsten carbide or the 60/40 blend.

Tips of Stellite can be brazed on to lathe and cutting tools of all types, giving an excellent cutting edge on a less brittle shank. Stellite, however, can be deposited directly on to surfaces, and in this form it is used for all types of duty, such as surfaces on shafts which have to stand up to great wear and corrosion, lathe centres, drill tips, etc.

Stelliting steel

Preparation. Scale, dirt and impurities are thoroughly removed and the parent metal is pre-heated. Pre-heating and slow cooling are essential to avoid cracking.

Small jets of water, playing on each side of the weld, can be used to limit the flow of heat and reduce distortion, when building up deposits on hardened parts such as camshafts.

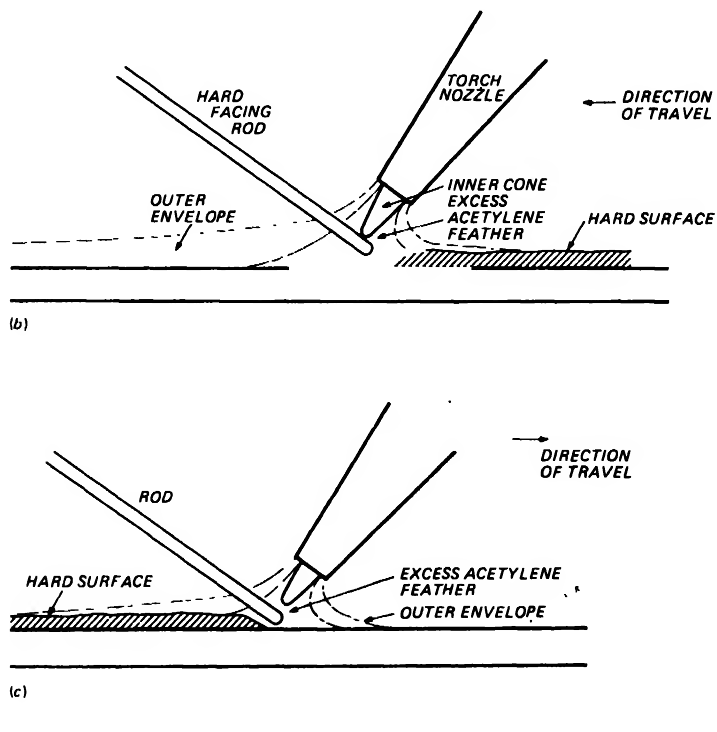
Flame and rod. A flame with an excess of acetylene is used, the white plume being about $2\frac{1}{2}$–3 times the length of the inner blue cone. Too little acetylene will cause the Stellite to foam and bubble, giving rise to blowholes, while too

much acetylene will cause carbon to be deposited around the molten metal. The tip should be one size larger than that for the same thickness steel plate, but the pressure should be reduced, giving a softer flame. For small parts 5 mm diameter Stellite rods can be used, while thicker rods are used for larger surfaces. Too much heat prevents a sound deposit being obtained, because some of the base metal may melt and mix with the molten stellite, thus modifying its structure.

Technique. The flame is directed on to the part to be surfaced, but the inner cone should not touch the work, both blowpipe and rod making an angle of 45–60° with the plate (Fig. 13.40*b* and *c*). When the steel begins to sweat the Stelliting rod is brought into the flame and a drop of Stellite melted on to the sweating surface of the base metal, and it will spread evenly and make an excellent bond with the base metal. The surfacing is continued in this way.

After treatment. The part should be allowed to cool out very slowly to prevent cracks developing.

Fig. 13.40. (*b*) and (*c*) Alternative methods of hard facing



Stelliting cast iron

Preparation. Clean the casting thoroughly of oil and grease and pre-heat to a dull red heat.

Technique. Using the same type rod and flame as for Stelliting steel, it is advisable first to lay down a thin layer and then build up a second layer on this. The reason for this is that more of the surface of the cast iron is melted than in the case of steel, and as a result the first layer of Stellite will be diffused with impurities from the cast iron.

The flame is then played on the cast iron and the rod used to push away any scale. A drop of Stellite is then flowed on to the surface, and the flame kept a little ahead of the molten pool so as to heat the cast iron to the right temperature before the Stellite is run on. Cast iron flux may be used to flux the oxide and produce a better bond.

Heat treatment for depositing Stellite

(*a*) Small components of mild steel and steel up to 0.4% carbon. Pre-heat with the torch the area to be faced; hard face the area and cool away from draughts.

(*b*) Large components of mild steel and steel up to 0.4% carbon; small components of high-carbon and low-alloy steels. Pre-heat to 250–350 °C. Hard face whilst keeping at this heat with auxiliary heating flame. Cover and bring to an even heat with flame and cool slowly in dry kieselguhr, mica, slaked lime, ashes or sand.

(*c*) Large components of high-carbon or low-alloy steel; cast iron components; bulky components of mild steel with large areas of Stellite facing. Pre-heat to 400–500°C. Hard face whilst at this temperature. Bring to a dull red even heat and cool slowly as for (*b*).

(*d*) Air-hardening steel (not stainless). When a large area of deposit is required these steels should be avoided. Otherwise pre-heat to 600–650 °C and deposit hard surface whilst at this heat. Then place in a furnace at 650 °C for 30 minutes and cool large components in the furnace and small ones as (*b*).

(*e*) 18/8 austenitic stainless steel non-hardening welding type. Pre-heat to 600–650 °C. Hard surface whilst at this temperature. Bring to an even temperature and cool out as (*b*).

(*f*) 12–14% manganese austentic steel. Use arc process.

Spray fuse process for depositing Stellite

In this process a stellite powder (HV 425–750) or nickel powder (HV 375–750) is sprayed on to the part to be hardened and this layer is then fused on with an oxy-acetylene flame. In this way thin layers up to 2 mm thick can be deposited having little dilution with the parent metal. The alloys are self-fluxing, the deposit has a fine structure, and any inclusions are well distributed. Surfaces having sharp corners and sudden change of section should be avoided and the areas should be rough turned and then shot blasted to obtain a rough surface. The hardfacing powder, cobalt based, nickel based or tungsten carbide, is applied with a gas spray gun using aspirating gas pressure to mix the powder and to disperse it evenly through the flame on to the pre-heated surface to be treated. The particles are in the form of a semi-molten spray when they hit the surface. Jobs should be pre-heated and the gun held about 150 mm from the surface, and after deposition the deposit is porous like other cold-sprayed deposits. The next operation is to fuse the deposit into a sound, wear-resistant coating securely bonded to the parent metal. Because of stresses remaining in the deposit, fusing should be carried out immediately after spraying. It is done with an oxy-acetylene torch with a multi-jet nozzle, the part being first raised to about 350°C. One area is selected to begin fusing and the temperature raised to 700–800°C over a small area and part of this is then raised to 1100°C when glazing of the surface begins, indicating that fusing is taking place. The torch is moved over the area until it is all fused and the whole part finally brought up to an even temperature, cooling being carried out by covering it with heat-insulating substance or heat treatment being given, if required for the parent plate.

With this method of application localized heat is reduced, so that distortion is minimized and thin deposits can be applied with little dilution. Shrinkage amounting to 25% takes place during fusing so this must be allowed for, together with grinding tolerance if required, when calculating the thickness of the sprayed coat.

In the manual torch powder method, the gun and torch are combined in one unit and deposition and fusing are carried out in one operation. The incoming gas is used for mixing and carrying the powder to the flame. The usual method of deposit is by using a carburizing flame with a feather about $2\frac{1}{2}$–3 times the length of the inner cone. A dilution of 1–5% occurs and the thickness of deposit is governed by the rate of flow of powder and movement of the torch (Fig. 13.41*a* and *b*).

Typical applications are: dies, cast iron parts, cement dies, fan blades, feed screws, hammer mill hammers, knives, cams and other metal-to-metal parts, plough shares, pump parts, bearing surfaces of steel shafts, etc. See

also hard facing by plasma spray, plasma transferred arc, mechanized TIG, MIG and MMA methods.

Brazing (see also Appendix 12 for rods and fluxes)

Brazing may be defined as 'a process of joining metals in which, during or after heating, molten filler metal is drawn by capillary attraction into the space between closely adjacent surfaces of the parts to be joined'. In general the melting point of the filler metal is above 500°C but always below the melting temperature of the parent metal.

Since capillarity and hence surface tension are involved in the process it may be convenient to give a brief explanation of some of the principles involved.

The student should refer to BS 1845 which lists the chemical compositions and approximate melting ranges of filler metals grouped under the following headings: aluminium brazing alloys, silver brazing alloys, copper–phosphorus brazing alloys, copper brazing alloys, brazing brasses, nickel-base brazing alloys, palladium bearing brazing alloys, and gold bearing brazing alloys.

Fig. 13.41. (*a*) Manual torch operation.

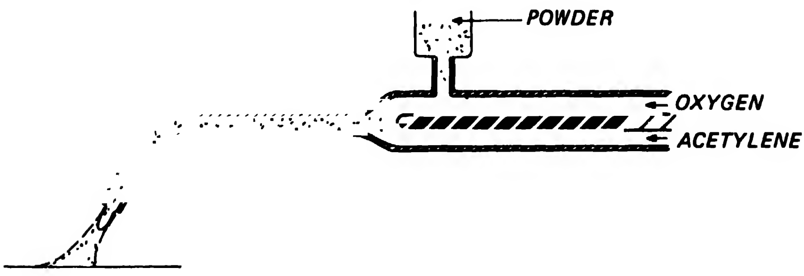
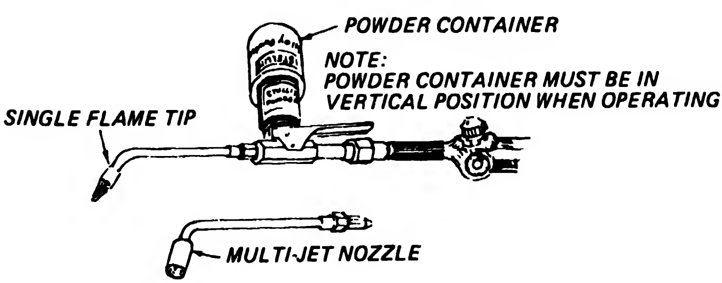


Fig. 13.41. (*b*) Manual power torch–stellite.



Surface tension

If drops of mercury rest on a level plate it will be noticed that the smaller the drop the more nearly spherical it is in shape, and if any drop is deformed it always returns to its original shape. If the only force acting on any drop were that due to its own weight, the mercury would spread out over the plate to bring its centre of gravity (the point at which the whole weight of the drop may be conceived to be concentrated) to the lowest point so that to keep the shape of the drop other forces must be present. As the drop gets smaller the force due to its own weight decreases and these other forces act so as to make the drop more spherical, that is to take up a shape which has the smallest surface area for a given volume. Other examples of these forces, termed surface tension, are the floating of a dry needle on the surface of water, soap bubbles and water dripping from a tap. In the first example the small dry needle must be laid carefully horizontally on the surface. If it is pushed slightly below the surface it will sink because of its greater density. Evidently the surface of the water exhibits a force (surface tension) which will sustain the weight of the needle. If a wire framework $ABCD$, with CD, length x, able to slide along BC and AD, holds a soap film, the film tends to contract, and to prevent this a force F must be applied at right angles to CD (Fig. 13.42). The surface tension is defined as the force per unit length S on a line drawn in the film surface, and since there are two surfaces to the film $F = 2Sx$.

Angle of contact(θ). The angle of contact between a liquid and a solid may be defined as the angle between the tangent to the liquid surface at the point of contact and the solid surface. For mercury on glass the contact angle is about 140°, while for other liquids the angle is acute and may approach zero (Fig. 13.43).

Fig. 13.42

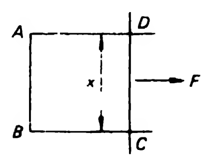
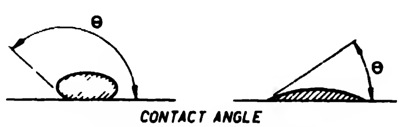


Fig. 13.43.



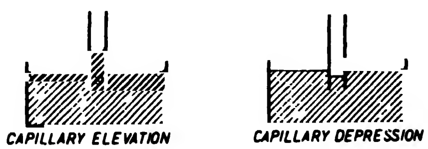
Wetting. If the contact angle approaches zero the liquid spreads and wets the surface and may do so in an upward direction. If the solid and liquid are such that the forces of attraction experienced by the molecules towards the interior of the liquid are less than the forces of attraction towards the solid, the area of contact will increase and the liquid spreads.

Capillarity. If a narrow bore (capillary) tube with open ends is placed vertically in a liquid which will wet the surface of the tube, the liquid rises in the tube and the narrower the bore of the tube the greater the rise. The wall thickness of the tube does not affect the rise and a similar rise takes place if the tube is replaced by two plates mounted vertically and held close together. If the tube or the plates are held out of the vertical the effect is similar and the vertical rise the same. If the liquid does not wet the tube (e.g. mercury) a depression occurs, and the shape of the liquid surface (the meniscus) is shown. The rise is due to the spreading or wetting action already considered – the liquid rises until the vertical upward force due to surface tension acting all round the contact surface with the tube is equal to the vertical downward force due to the weight of the column of liquid (Fig. 13.44).

This wetting action and capillary attraction are involved in the brazing process. The flux, which melts at a lower temperature than the brazing alloys, wets the surface to be brazed, removes the oxide film and gives clean surfaces which promote wetting by a reduction of the contact angle between the molten filler alloy and the parent plate at the joint. The molten filler alloy flows into the narrow space or joint between the surfaces by capillary attraction and the narrower the joint the further will be the capillary flow. Similarly solder flows into the narrow space between tube and union when 'capillary fittings' are used in copper pipe work.

Brazing can be performed on many metals including copper, steel and aluminium, and in all cases cleanliness and freedom from grease is essential. The filler alloy used for aluminium brazing has already been mentioned in the section on oxy-acetylene welding. In the case of the nickel alloys, time and temperature are important. For example copper alloys mix readily with nickel alloy 200 or MONEL® alloy 400 and can pick up sufficient

Fig. 13.44



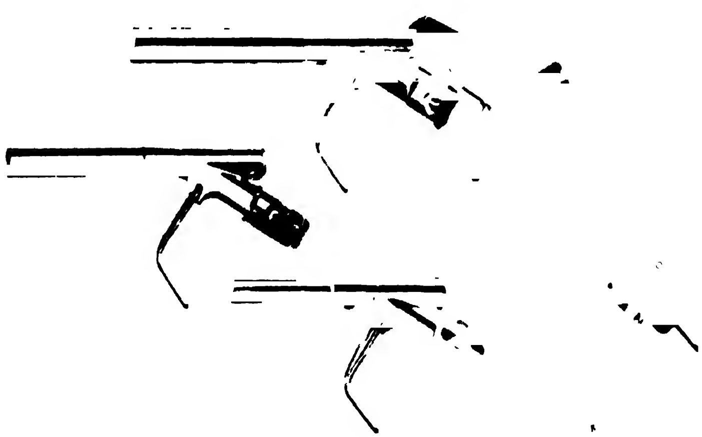
nickel to raise the melting point and hinder the flow of the filler metal. Also chromium and aluminium form refractory oxides which make brazing difficult, so that the use of a flux is necessary. A wide range of brazing alloys are available having a variety of melting points. Fig. 13.45 shows a modern brazing torch using LPG. See appendix for table of general purpose silver brazing alloys and fluxes.

Aluminium brazing

The fusion welding of fillet and lap joints in thin aluminium sections presents considerable difficulty owing to the way in which the edges melt back. In addition the corrosive fluoride flux is very liable to be entrapped between contracting metal surfaces so it is advantageous to modify the design wherever possible so as to include butt joints instead of fillet and lap.

In many cases, however, corner joints are unavoidable and in these cases flame brazing overcomes the difficulty. It can be done more quickly and cheaply than fusion welding, less skill is required and the finished joint is neat and strong.

Fig. 13.45. LP gas brazing torch for brazing, hard and soft soldering. Propane gas recommended, cylinder pressure 7–8 bar. Standard torch pressure 4 bar. Use smaller nozzles for smaller flames. Temperatures up to 950 °C, piezo-electric ignition.



Aluminium brazing is suitable for pure aluminium and for alloys such as LM4, LM18 and for the aluminium–manganese and aluminium–manganese–magnesium alloys, as long as the magnesium content is not greater than 2%.

Preparation. It is always advisable to allow clearance at the joints since the weld metal is less fluid as it diffuses between adjacent surfaces. Clearance joints enable full penetration of both flux and filler rod to be obtained.

Surface oxide should be removed by wire brush or file and grease impurities by cleaning or degreasing. Burrs such as result from sawing or shearing and other irregularities should be removed so that the filler metal will run easily across the surface. Socket joints should have a 45° belling or chamfer at the mouth to allow a lead in for the flux and metal, and to prevent possibility of cracking on cooling, the sections of the surfaces to be jointed should be reduced to approximately the same thickness where possible.

Blowpipe, flame, flux and rod. The blowpipe and rod are held at the normal angle for leftward welding, and a nozzle giving a consumption of about 700 litres of both oxygen and acetylene each per hour is used. The flame is adjusted to the excess acetylene condition with the white acetylene plume approximately $1\frac{1}{2}$ to 2 times the length of the inner blue cone. The rod can be of 10–13% silicon–aluminium alloy melting in the range 565–595°C (compared with 659°C for pure aluminium). This is suitable for welding and brazing the high silicon aluminium alloys and for general aluminium brazing. Another type of rod containing 10–13% Si and 2–5% Cu is also used for pure aluminium and aluminium alloys except those with 5% silicon, or with more than 2% magnesium, but is not so suitable due to its copper content if corrosive conditions are to be encountered, but it has the advantage of being heat-treatable after brazing, giving greater mechanical strength.

BS 1845, Filler metals for brazing

	Major alloying elements only (%)				Melting range (°C)	
Type	Silicon	Copper	Iron	Aluminium	Solidus	Liquidus
AL1	10–13	2–5	0.6	Rem	535	595
AL2	10–13	0–0.1	0.6	Rem	565	595
AL3	7–8	0–0.1	—	Rem	565	610
AL4	4.5–6.0	0–0.1	—	Rem	565	630

In general, ordinary finely divided aluminium welding flux prepared commercially is quite suitable for brazing, but there is also available a brazing flux of similar composition which has a lower melting point.

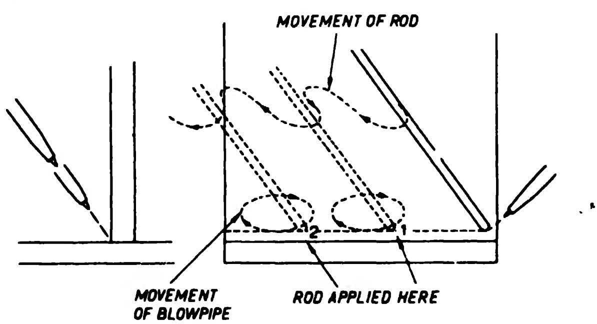
Technique. The flame is held well away from the joint to be brazed and pre-heating is done with the outer envelope of the flame for about three minutes – this procedure ensures an even temperature, which is essential so that first the flux flows evenly into the joint followed by the filler metal which must displace *all* the flux, otherwise if islands of flux are entrapped corrosion of the joint will occur.

The rod is warmed, dipped in the flux and the tuft which adheres to the rod is touched down on the heated joint. When the correct temperature has been reached the flux will melt and flow over and between the surfaces smoothly and easily. The blowpipe is now lowered to the normal welding position, some rod is melted on to the joint and the blow-pipe moved forward along the seam running the filler rod into the joint. The blowpipe is then raised and brought back a little and lowered again, the above operation being repeated – the blowpipe thus describes an elliptical motion – each operator modifying the technique according to his individual style (Fig. 13.46).

Flux should only be added when the filler rod does not appear to be running freely. Too much flux is detrimental to the finished joint and great care should be taken that the filler rod flows freely into the joint, so as to displace all the flux.

After treatment. The corrosive flux should be removed by the treatment as given for aluminium welding.

Fig. 13.46. Aluminium brazing



General precautions

The following general precautions should be taken in welding:

(1) Always use goggles of proved design when welding or cutting. The intense light of the flame is harmful to the eyes and in addition small particles of metal are continually flying about and may cause serious damage if they lodge in the eyes. Welding filters or glasses are graded according to BS 679 by numbers followed by the letters GW or GWF. The former are for welding operations without a flux and the latter with flux because there is an additional amount

Table giving some of the chief types of oxy-acetylene welding rods available for welding carbon and alloy steels.

Rod	Description and use
Low-carbon steel	A general purpose rod for mild steel. Easily filed and machined. Deposit can be case-hardened.
High-tensile steel	Gives a machinable deposit of greater tensile strength than the previous rod. Can be used instead of the above wherever greater strength is required.
High-carbon steel	Gives a deposit which is machinable as deposited, but which can be heat treated to give a hard abrasion-resisting surface. When used for welding broken parts, these should be of high carbon steel, and heat treatment given after welding.
High-nickel steel ($3\frac{1}{2}$–4%)	Produces a machinable deposit with good wear-resisting properties. Suitable for building up teeth in gear and chain wheels, splines and keyways in shafts, etc.
Wear-resisting steel (12–14% manganese)	Gives a dense tough unmachinable deposit which must be ground or forged into shape, and can be heat treated. Useful for building up worn sliding surfaces, cam profiles, teeth on excavators, tracks, etc.
Stellite	For hard surfacing and wear- and abrasion-resisting surfaces.
Chrome molybdenum steel (creep resisting)	High-tensile alloy steel deposit for pressure vessels and high-pressure steam pipes, etc. Rod should match the analysis of the parent metal.
Chrome-vanadium steel	A high-tensile alloy rod for very highly stressed parts.
Tool steel	Suitable for making cutting tools by tipping the ends of mild or low-carbon steel shanks.
Stainless steel	Decay-proof. Rod should match the analysis of the parent metal.

of glare. The grades range from 3/GW and 3/GWF to 6/GW and 6/GWF, the lightest shade having the lowest grade number. For aluminium welding and light oxy-acetylene cutting, 3/GW or 3/GWF is recommended, and for general welding of steel and heavier welding in copper, nickel and bronze, 5/GW or 5/GWF is recommended. A full list of recommendations is given in the BS.

(2) When welding galvanized articles the operator should be in a well-ventilated position and if welding is to be performed for any length of time a respirator should be used. (In cases of sickness caused by zinc fumes, as in welding galvanized articles or brass, milk should be drunk.)

(3) In heavy duty welding or cutting and in overhead welding, asbestos or leather gauntlet gloves, ankle and feet spats and protective clothing should be worn to prevent burns. When working inside closed vessels such as boilers or tanks, take every precaution to ensure a good supply of fresh air.

(4) In welding or cutting tanks which have contained inflammable liquids or gases, precautions must be taken to prevent danger of explosion. One method for tanks which have contained volatile liquids and gases is to pass steam through the tank for some hours according to its size. Any liquid remaining will be vaporized by the heat of the steam and the vapours removed by displacement.

Tanks should never be merely swilled out with water and then welded; many fatal explosions have occurred as a result of this method of preparation. Carbon dioxide in the compressed form can be used to displace the vapours and thus fill the tank, and is quite satisfactory but is not always available. Tanks which have contained heavier types of oil, such as fuel oil, tar, etc., present a more difficult problem since air and steam will not vaporize them. One method is to fill the tank with water, letting the water overflow for some time. The tank should then be closed and turned until the fracture is on top. The water level should be adjusted (by letting a little water out if necessary) until it is just below the fracture. Welding can then be done without fear as long as the level of the water does not drop much more than a fraction of an inch below the level of the fracture.

The welder should study the Department of Employment memorandum on *Safety measures for the use of oxy-acetylene equipment in factories* (Form 1704). Toxic gases and fine airborne particles can provide a hazard to a welder's health. The Threshold Limit Value (TLV) is a system by which concentrations of these are classified, and is explained in the Department of Employment Technical data notes No. 2, *Threshold limit values.*

Relevant publications. *Safe working, maintenance and repair of gas cylinder and pipeline regulators used with compressed gases for welding, cutting and related processes* (BCGA CP1).

Safe working, maintenance and repair of hand held oxygen and fuel-gas blowpipes used for welding, cutting and related processes (BCGA CP2).

Technical Information sheets; TIS 1 *Pressure gauges*, TIS2 *Hoses.*

All the above together with British Acetylene Association publications may be obtained from the British Compressed Gases Association, 93 Albert Embankment, London SE1 7TU.

In the 'Health and Safety at Work' series *Noise and the worker No. 25* and *Welding and flame-cutting using compressed gases No. 50* are obtainable from Her Majesty's Stationery Office.

14

Cutting processes

Gas cutting of iron and steel

Iron and steel can be cut by the oxy-hydrogen, oxy-propane, oxy-natural gas and oxy-acetylene cutting blowpipes with ease, speed and a cleanness of cut.

Principle of cutting operation

There are two operations in gas cutting. A heating flame is directed on the metal to be cut and raises it to bright red heat or ignition point. Then a stream of high-pressure oxygen is directed on to the hot metal. The iron is immediately oxidized to magnetic oxide of iron (Fe_3O_4) and, since the melting point of this oxide is well below that of the iron, it is melted immediately and blown away by the oxygen stream.

It will be noted that the metal is cut entirely by the exothermic chemical action and the iron or steel itself is not melted. Because of the rapid rate at which the oxide is produced, melted and blown away, the conduction of the metal is not sufficiently high to conduct the heat away too rapidly and prevent the edge of the cut from being kept at ignition point.

The heat to keep the cut going once it has started is provided partly by the heating jet, and partly by the heat of the chemical action.

The cutting torch or blowpipe (Fig. 14.1)

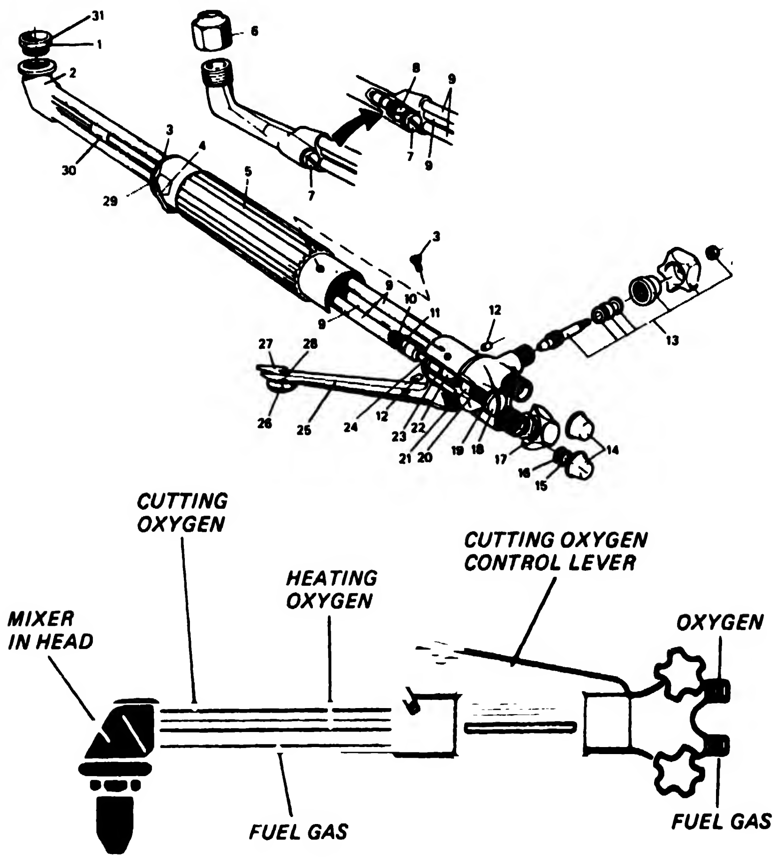
Cutting blowpipes may be either high or low pressure. The high pressure pipe, using cylinder acetylene or propane as the fuel gas,* can have the mixer in the head (Fig. 14.2), or in the shank, while the low pressure pipe with injector mixing can be used with natural gas at low pressure.

* Proprietary gases are available and contain mixtures of some of the following: methyl acetylene, propadiene, propylene, butane, butadiene, ethane, methane, diethyl ether, dimethyl ether, etc

In the high pressure pipe, fuel gas and heating oxygen are mixed in the head (Fig. 14.2), and emerge from annular slots for propane or holes for acetylene (Fig, 14.4).

The cutting oxygen is controlled by a spring loaded lever, pressure on which releases the stream of cutting oxygen which emerges from the central

Fig. 14.1. Cutter.



Key:

1 Nozzle nut.
2. Head 90°
Head 75°.
Head 180°.
3. Screw.
4. Bracket latch.
5. Handle.
6. Nozzle nut
7. Injector cap.
8. Injector assembly.
9. Tube.
9a Tube.
10 Push rod
11. Lock nut
12. Pivot pin.
13 Control valve fuel gas.
14. Red cap.
15 Spring clip
16. Filter.
17. Control valve oxygen.
18. Rear cap
19 Cap washer.
20. Valve spring disc.
21. Rear valve.
22. Plunger.
23. O ring.
24. Lever pin.
25. Lever.
26. Button.
Grub screw.
27 Lever latch.
28. Spring washer.
29. Forward tube
30. Tube support.
31. Nut.

orifice the diameter of which increases as thickness of plate to be cut increases. An oxygen gauge giving a higher outlet pressure (up to 10 bar) than for welding is required, but the gauge for cylinder acetylene can be the same with pressures up to 1.3 bar. Propane pressure is usually up to 3.5 bar and if natural gas is used no regulator is required but a non-return valve should be fitted in the supply line to prevent flash back.

The size of blowpipe used depends upon whether it is for light duty or

Fig. 14.2.

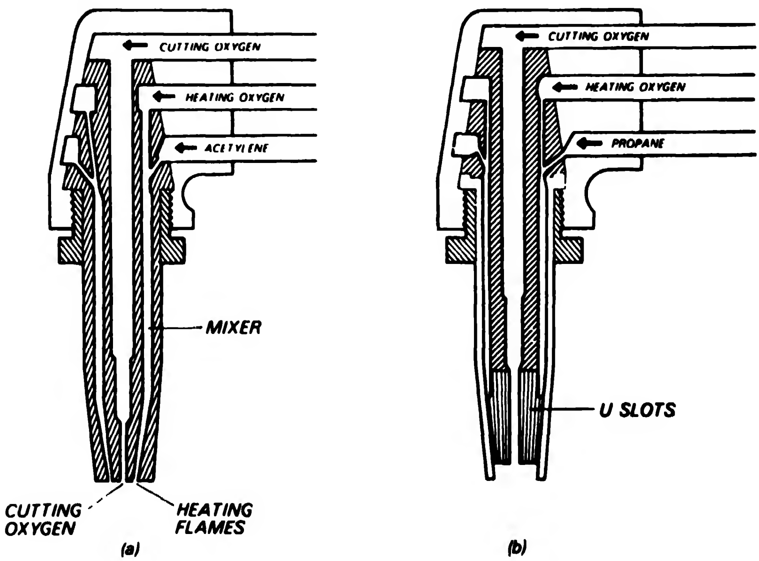
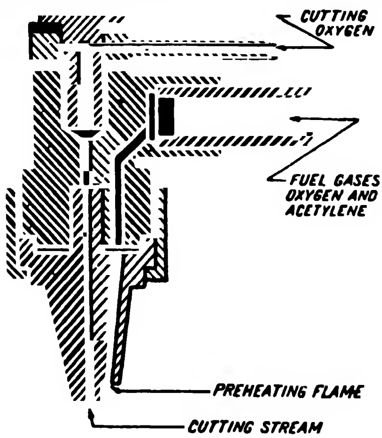


Fig. 14.3. Cutting head for thin steel sheet.



heavy continuous cutting and the volume of oxygen used is much greater than of fuel gas (measured in litres per hour, l/h).

Fig. 14.3 shows a stepped nozzle used for cutting steel sheet up to 4 mm thick and this type is also available with head mixing.

The size of torch varies with the thickness of work it is required to cut and whether it is for light duty, or heavy, continuous cutting.

Adjustment of flame

Oxy-hydrogen and Oxy-propane. The correctly adjusted pre-heating flame is a small non-luminous central cone with a pale blue envelope.

Oxy-natural gas. This is adjusted until the luminous inner cone assumes a clear, definite shape, that may be up to 8–10 mm in length for heavy cuts.

Oxy-acetylene. This flame is adjusted until there is a circular short blue luminous cone, if the nozzle is of the concentric ring type, or until there is a series of short, blue, luminous cones (similar to the neutral welding flame), if it is of the multi-hole type (Fig. 14.5*a* and *b*). The effect of too much oxygen is indicated in Fig. 14.5*c*.

Fig. 14.4

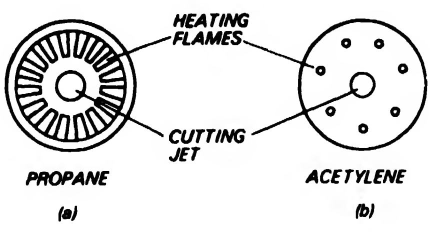
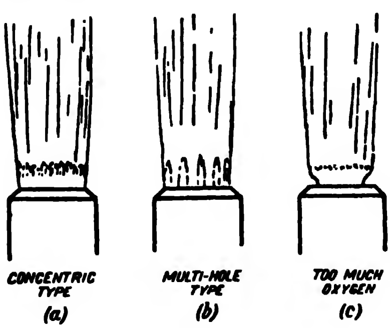


Fig. 14.5.



It may be observed that when the cutting valve is released the flame may show a white feather, denoting excess acetylene. This is due to the slightly decreased pressure of the oxygen to the heating jet when the cutting oxygen is released. The flame should be adjusted in this case so that it is neutral when the cutting oxygen is released.

Care should be taken to see that the cutter nozzle is the correct size for the thickness to be cut and that the oxygen pressure is correct (the nozzle sizes and oxygen pressures vary according to the type of blowpipe used).

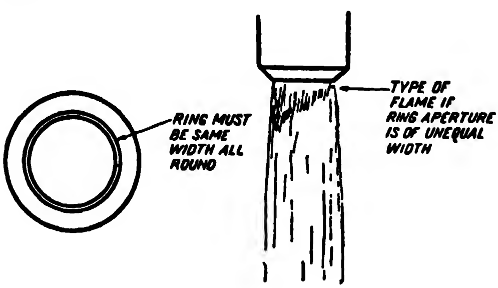
The nozzle should be cleaned regularly, since it becomes clogged with metallic particles during use. In the case of the concentric type of burner, the outer ring should be of even width all round, otherwise it will produce an irregular-shaped inner cone, detrimental to good cutting (Fig. 14.6).

Technique of cutting

The surface of the metal to be cut should be free of grease and oil, and the heating flame held above the edge of the metal to be cut, farthest from the operator, with the nozzle at right angles to the plate. The distance of the nozzle from the plate depends on the thickness of the metal to be cut, varying from 3 to 5 mm for metal up to 50 mm thick, up to 6 mm for metal 50 to 150 mm thick. Since the oxide must be removed quickly to ensure a good, clean cut, it is always preferable to begin on the edge of the metal.

The metal is brought to white heat and then the cutting valve is released, and the cut is then proceeded with at a steady rate. If the cutter is moved along too quickly, the edge loses its heat and the cut is halted. In this case, the cutter should be returned to the edge of the cut, the heating flame applied and the cut restarted in the usual manner. Round bars are best nicked with a chisel, as this makes the starting of the cut much easier. Rivet heads can be cut off flush by the use of a special type nozzle while if galvanized plates are to be cut for any length of time, a respirator is advisable, owing to the poisonous nature of the fumes.

Fig. 14.6



To cut a girder, for example, the cut may be commenced at *A* and taken to *B* (Fig. 14.7). Then commenced at *C* and taken to *B*, that is, the flange is cut first. Then the bottom flange is cut in a similar manner. The cut is then commenced at *B* and taken to *E* along the web, this completing the operation. By cutting the flanges first the strength of the girder is altered but little until the web itself is finally cut.

Rollers and point guides can be affixed to the cutter in order to ensure a steady rate of travel and to enable the operator to execute straight lines or circles, etc., with greater ease (Fig. 14.8*a*).

The position of the flame and the shape of the cut are illustrated in Fig. 14.8*b*.

To close down, first shut off the cutting stream, then the propane or acetylene and then the oxygen valve. Close the cylinder valves and release the pressure in the tubes by momentarily opening the cutter valves.

To cut holes in plates a slightly higher oxygen pressure may be used. The spot where the hole is required is heated as usual and the cutting valve

Fig. 14.7

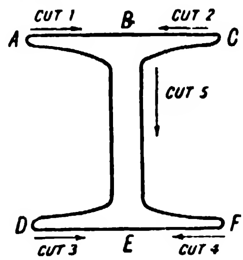
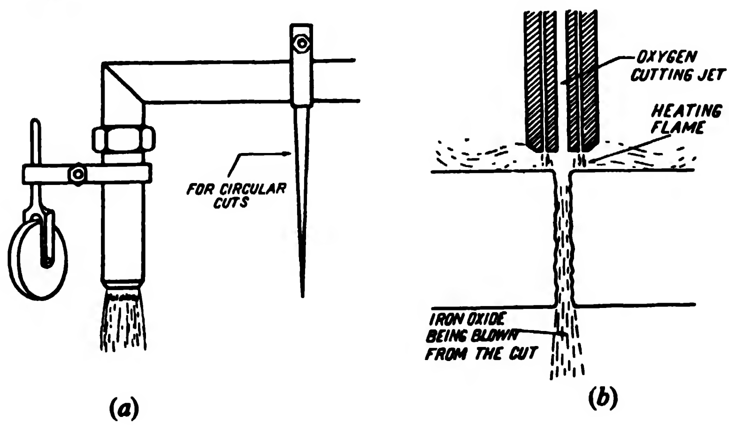


Fig. 14.8



released gently, at the same time withdrawing the cutter from the plate. The extra oxygen pressure assists in blowing away the oxide, and withdrawing the nozzle from the plate helps to prevent oxide from being blown on to the nozzle and clogging it. The cutting valve is then closed and the lower surface now exposed is heated again, and this is then blown away, these operations continuing until the hole is blown through. The edges of the hole are easily trimmed up afterwards with the cutter.

When propane or natural gas is used instead of acetylene, the flame temperature is lower; consequently it takes longer to raise the metal to ignition point and to start the cut, and it is not suitable for hand cutting over 100 mm thick nor for cast iron cutting. Because of this lower temperature, the speed of cutting is also slower. The advantages, however, are in its ease of adjustment and control; it is cheap to instal and operate and, most important of all, since the metal is not raised to such a high temperature as with the oxy-acetylene flame, the rate of cooling of the metal is slower and hence the edges of the cut are not so hard. This is especially so in the case of low-carbon and alloy steels. For this reason, oxy-propane or natural gas is often used in works where cutting machines are operated (see later).

The oxy-hydrogen flame can also be used (the hydrogen being supplied in cylinders, as the oxygen). It is similar in operation to oxy-propane and has about the same flame temperature. It is advantageous where cutting has to be done in confined spaces when the ventilation is bad, since the products of combustion are not so harmful as in the case of oxy-acetylene and oxy-propane, but is not so convenient and quick to operate.

The effect of gas cutting on steel

It would be expected that the cut edge would present great hardness, owing to its being raised to a high temperature and then subjected to rapid cooling, due to the rapid rate at which heat is dissipated from the cut edges. Many factors, however, influence the hardness of the edge.

Steels of below 0.3% carbon can be easily cut, but the cut edges will definitely harden, although the hardness rarely extends more than 3 mm inwards and the increase is only 30 to 50 points Brinell.

Steels of 0.3% carbon and above and also alloy steels are best preheated before cutting, as this reduces the liability to crack.

Nickel, molybdenum, manganese and chrome steels (below 5%) can be cut in this way. Steels having a high tungsten, cobalt or chrome content, however, cannot be cut satisfactorily. Manganese steel, which is machined

with difficulty owing to the work hardening, can be cut without any bad effects at all.

The oxy-acetylene flame produces greater hardening effect than the oxy-propane flame, as before mentioned, owing to its higher temperature. Excessive cutting speeds also cause increased hardness, since the heat is thereby confined to a narrower zone near the cut and cooling is thus more rapid. Similarly, a thick plate will harden more than a thin one, owing to its more rapid rate of cooling from the increased mass of metal being capable of absorbing the heat more quickly. The hardening effect for low carbon steels, however, can be removed either by preheating or heat treatment after the cut. The hardening effect in mild steel is very small. On thicknesses of plate over 12 mm it is advisable to grind off the top edge of the cut, as this tends to be very hard and becomes liable to crack on bending.

The structure of the edges of the cut and the nearby areas will naturally depend on the rate of cooling. Should the cutting speed be high and the cooling be very rapid in carbon steels, a hard martensitic zone may occur, while with a slower rate of cutting and reduced rate of cooling the structure will be softer. A band of pearlite is usually found, however, very near to the cut edges and because of this, the hardness zone, containing increased carbon, is naturally very narrow. When the cut edge is welded on directly, without preparation, all this concentration of carbon is removed.

Thus, we may say that, for steels of less than 0.3% carbon, if the edges of the cut are smooth and free from slag and loose oxide, the weld can be made directly on to the gas-cut edge without preparation.

Oxygen or thermic lance

This is a method of boring or cutting holes in concrete, brick, granite, etc., by means of the heat generated by chemical reactions.

The lance consists of a tube about 3 m long and 6.5–9.5 mm diameter which is packed with steel wires. One end of the tube is threaded or snap connected and is connected by means of a flexible hose to an oxygen supply. To operate the lance the free end is heated and oxygen passed down the tube. Rapid oxidation of the wires begins at the heated end with great evolution of heat. Magnesium and aluminium are often added to the packing to increase the heat output. The operator can be protected by a shield and protective clothing should be worn. The exothermic reaction melts concrete and other hard materials to a fluid slag and cast iron is satisfactorily bored. Standard gas pipe can be used for thick steel sections.

As an example, a hole of 30 mm diameter and 300 mm deep can be bored

in concrete using 1.9 m of lance and 1.0–1.3 m^3 of oxygen at a pressure of 7 bar (100 lb per in^2) in 120 seconds.

Cutting machines

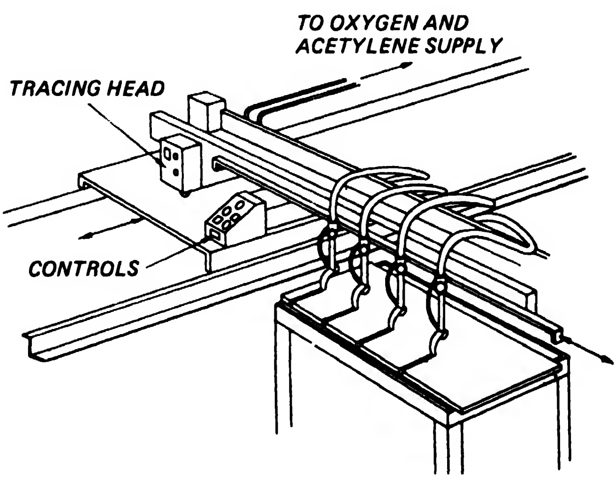
Profiles cut by hand methods are apt to be very irregular and, where accuracy of the cut edge is required, cutting machines are used. The heating flame is similar to that used in the hand cutter and is usually oxy-propane or oxy-acetylene (either dissolved or generated), while the thickness of the cut depends on the nozzle and gas pressures.

The mechanical devices of the machine vary greatly, depending upon the type of cut for which they are required. In many types a tracing head on the upper table moves over the drawing or template of the shape to be cut. Underneath the table or on the opposite side of the machine (depending on the type) the cutting head describes the same motion, being worked through an intermediate mechanism. The steel being cut is placed on supports below the table (Fig. 14.9*a* and *b*).

Simpler machines for easier types of cuts, such as straight line and circles, bevels, etc., are also made.

A typical machine is capable of cutting from 1.5 mm to 350 mm thick, 3 m in a straight line and up to 1.5 m diameter circle. The machine incorporates a magnetic tracing roller, which follows round a steel or iron template the exact shape of the cut required, while the cutting head cuts the replica of this shape below the table.

Fig. 14.9. (*a*) Cutting machine fitted with four cutting heads.



Stack cutting

Thin plates which are required in quantities can be cut by clamping them tightly in the form of a stack and, due to the accuracy of the modern machines, this gives excellent results and the edges are left smooth and even. Best results are obtained with a stack 75 100 mm thick, while G clamps can be used for the simpler types of stack cutting.

Cast iron cutting

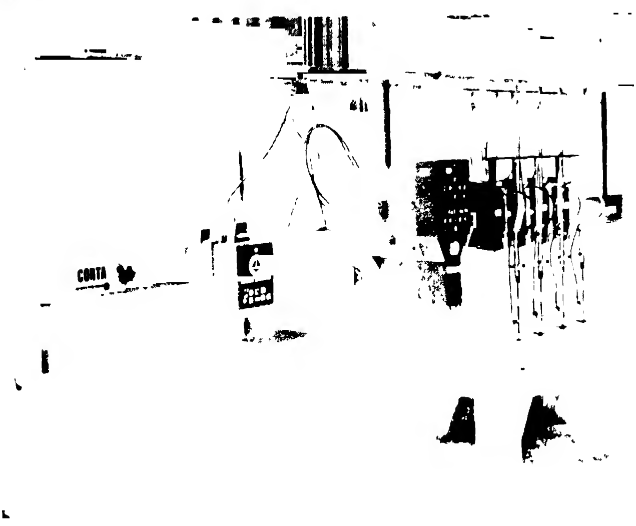
Cast iron cutting is made difficult by the fact that the graphite and silicon present are not easily oxidized. Reasonably clean cuts can now be made, however, using a blowpipe capable of working at high pressure of oxygen and acetylene. Cast iron cannot be cut with hydrogen.

Since great heat is evolved in the cutting process, it is advisable to wear protective clothing, face mask and gloves.

The oxygen pressure varies from 7 N/mm² for 35 mm thick cast iron to 11 N/mm² for 350 to 400 mm thick, while the acetylene pressure is increased accordingly.

The flame is adjusted to have a large excess of acetylene, the length of the white plume being from 50-100 mm long (e.g. 75 mm long for 35–50 mm thick plate). The speed of cutting is low, being about 2.5 m per hour for 75–125 mm thick metal.

Fig. 14.9. (*b*)



Technique. The nozzle is held at 45° to the plate with inner cone 5–6 mm from the plate, and the edge where the cut is to be started is heated to red heat over an area about 12–18 mm diameter. The oxygen is then released and this area burnt out. The blowpipe is given a zig-zag movement, and the cut must not be too narrow or the slag and metal removed will clog the cut. About 12 to 18 mm is the normal width. After the cut is commenced the blowpipe may be raised to an angle of 70–80°, which will produce a lag in the cut, as shown in Fig. 14.10.

Owing to the fact that high pressures are used in order to supply sufficient heat for oxidation, large volumes of gas are required, and this is often obtained by connecting several bottles together.

Flame gouging by the oxy-acetylene process

Flame gouging is an important extension of the principle of oxy-acetylene cutting by which grooves with very smooth contours can be cut easily in steel plates without the plate being penetrated.

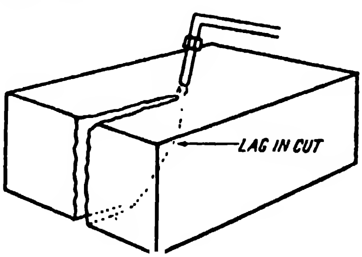
Principle of operation

This is the same as that in the oxy-acetylene process, except that a special type of nozzle is used in the standard cutting blowpipe. A pre-heating flame heats the metal to red heat (ignition temperature), the cutting oxygen is switched on, oxidation occurs and the cut continues as previously explained.

Equipment

The cutting torch may have a straight 75° or 180° angle head together with a range of special gouging nozzles, as shown in Fig. 14.11. The nozzle sizes are designated by numbers and they are bent at an angle which is best for the gouging process. Regulators and other equipment are as for cutting.

Fig. 14.10



Operation

There are two main techniques:

(1) progressive,

(2) spot.

In the former the groove is cut continuously along the plate – it may be started at the plate edge or anywhere in the plate area. It can be used for removing the underbeads of welds prior to depositing a sealing run, or it may be used for preparing the edges of plates. Spot gouging, however, is used for removing small localized areas such as defective spots in welds.

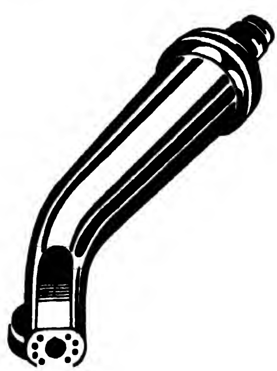
To start the groove at the edge of a plate for continuous or progressive gouging the nozzle is held at an angle of about 20° so that the pre-heating flames are just on the plate and when this area gets red hot the cutting oxygen stream is released and at the same time the nozzle is brought at a shallower angle to the plate as shown, depending upon depth of gouge required. The nozzle is held so that the nozzle end clears the bottom of the cut and the pre-heating flames are about 1.5 mm above the plate.

The same method is adopted for a groove that does not start at the plate edge. The starting point is pre-heated with the nozzle making a fairly steep angle with the plate at 20–40°. When the pre-heated spot is red hot the cutting oxygen stream is released and the angle of the nozzle reduced to 5–10° depending upon the depth of gouge required (Fig. 14.12).

To gouge a single spot, it is pre-heated as usual where required, but when red hot and the cutting stream of oxygen is turned on, the angle of the nozzle is *increased* (instead of, as previously, decreased) so as to make the gouge deep.

The depth of groove cut depends upon nozzle size, speed of progress and angle between nozzle and plate (i.e. angle at which the cutting stream of oxygen hits the plate). The sharper this angle, the deeper the groove. If the

Fig. 14.11. Flame gouging nozzle.



cutting oxygen pressure is too low ripples are left on the base of the groove. If the pressure is too high the cut at the surface proceeds too far in advance of the molten pool, and eventually the cut is lost and must be restarted.

Use of flame gouging

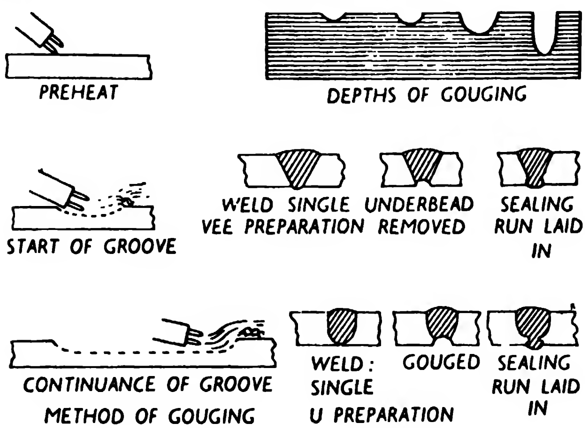
Certain specifications, such as those for fabrication of butt welded tanks, etc., stipulate that the underbead (or back bead) should be removed and a sealing run laid in place. This can easily and efficiently be done by flame gouging, as also can the removal of weld defects, tack welds, lugs, cleats, and also the removal of local areas of cracking in armour plate, and flashing left after upset welding (Fig. 14.13).

Oxy-arc cutting process

In this process the electric arc takes the place of the heating flame of the oxy-acetylene cutter. The covered electrodes of mild steel are in 4 sizes and are of tubular construction, the one selected depending upon whether it is required for cutting, piercing, gouging, etc. They are about 5 to 6 mm outside diameter with a fine hole about 1.5 mm diameter or more through which the cutting oxygen stream passes, down the centre. The gun type holder secures the electrode by means of a split collet and has a trigger controlling the oxygen supply. A d.c. or a.c. supply of 100–300 A is suitable.

The arc is struck with the oxygen off, the oxygen valve is released immediately and cutting begins, the electrode being held at an angle of 60° to the line of cut, except at the finish when it is raised to 90°, and is

Fig. 14.12. Method and uses of flame gouging.



consumed in the process. The oxygen pressure varies with the thickness of steel and with the size of electrode being used, about 4 bar (60 lb per in^2) for mild and low alloy steel plate of 8 to 10 mm thick and about 4.5–5.5 bar (70–80 lb per $in.^2$) for 23 to 25 mm thick. In addition to mild and low-alloy steel, and stainless steel copper, bronze, brass, monel and cupro-nickels can be roughly cut by this process.

Arc-air cutting and gouging process

In this process a carbon arc is used with a d.c. supply from a welding generator, or rectifier, together with a compressed air supply at 5–8 N/mm^2.

The equipment comprises a holder for the carbon electrode to which is supplied the first current with *electrode* +ve, and the compressed air which is controlled by a lever-operated valve on the electrode holder.

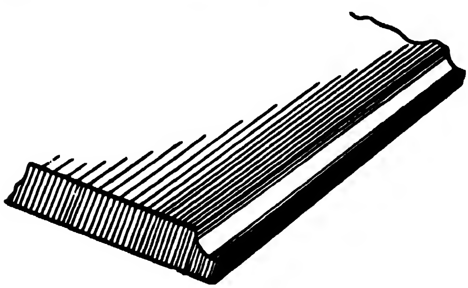
The jaws of the electrode holder are rotatable enabling the carbon electrode to be held in any position and twin jets of compressed air emerge from the head on each side of the carbon and parallel to it, the two jet streams converging at the point where the arc is burning. Air is also circulated internally in the holder to keep it cool.

Operation

The carbon electrode is placed in the holder with 75–150 mm projecting, with the twin jet holes pointing towards the arc end of the carbon.

The carbon is held at approximately 45° to the job to be cut while for shallow gouging the angle may be reduced to 20°. This angle together with the speed of travel affects the depth of cut. The carbons have been specially designed for the process and are a mixture of carbon and graphite covered over all with a thin sheath of copper. The copper coating prevents tapering

Fig. 14.13. Flame-gouged edge of plate, prepared for welding.



and ensures a cut of regular width in addition to enabling higher current to be used and consequently greater speeds of cutting to be obtained.

The carbons range in diameter from 4 mm (75–150 A) to 16 mm (550–700 A) and the higher the current density the more efficient the operation. Too high a current for a given size of electrode destroys the copper coating and burns the carbon at an excessive rate. Normally the copper coating burns away about 20 mm from the arc.

The process is applicable to work in all positions and is used for removing defects in castings, in addition to cutting and gouging. A reasonably clean surface of cut is produced with no adverse effect so that welding can be carried out on the cut surface without further grinding.

Cutting (and gouging) with the carbon arc. The carbon arc, owing to its high temperature, can be used for cutting steel. A high current is required, and the cut must be started in such a spot that the molten metal can flow away easily. The cut should also be wide enough so that the electrode (of carbon or graphite) can be used well down in it, especially when the metal is thick, so as to melt the lower layers. Cast iron is much more difficult to cut, since the changing of the iron into iron oxide is not easily performed owing to the presence of the graphite. Carbon arc cutting does not produce a neat cut, and because of this is only used in special circumstances. Gouging is performed with a very high current and the carbon is held at an angle of 45° to the work. This process is little used as it is very noisy.

Plasma cutting

(see also pp. 532–7, Ions and plasma)

This process gives clean cuts at fast cutting speeds in aluminium, mild steel and stainless steel. All electrically conducting materials can be cut using this process, including the rare earth metals and tungsten and titanium and it has superseded powder cutting.

The arc is struck between the electrode and the conducting body of the torch. A gas mixture or air passes under pressure through the restricted nozzle orifice and around the arc, emerging as a high-temperature (up to 25000 °C) ionized plasma stream, and the arc is transferred from the nozzle and passes between the electrode and work (Fig. 14.14).

Great improvements have been made in plasma cutting torches by greatly constricting the nozzle and thus narrowing the plasma stream, giving a narrower and cleaner cut with less consumption of power. In certain cases 'double arcing' may occur, in which the main arc jumps from tungsten electrode to nozzle and then to work, damaging both nozzle and electrode.

Power unit

A 24 kVA fan cooled unit has input voltages of 220, 380–415, and 500 and cutting currents ranging from 50 A minimum to 240 A maximum at 100% duty cycle and OCV of 200 V d.c. with heavy duty rectifiers for main and pilot arc control. An automatic pilot arc switch cuts off when the cutting arc is transferred. This size of unit enables metal of up to 40 mm thickness to be cut and edges prepared quickly and cleanly in stainless steel, alloy steels, aluminium and copper (Fig. 14.15).

A 75 kVA unit of similar input voltage has cutting currents of 50–250 A with OCV of 300 V and cutting voltage of 170 V enabling thicknesses of 2.7 to 50 mm upwards, in the previously mentioned materials, to be cut and edges prepared at high speed. The cutting head of either unit can be fitted to a carriage to obtain high speeds of cut with greater precision than with manual cutting.

The gases used are argon, hydrogen, nitrogen, and it should be noted that since high voltages of up to 300 V on open circuit and about 170 V during the cutting process, are encountered, great care should be taken to follow all safety precautions and avoid contact with live parts of the torch when the unit is switched on. All work to be done on the torch head should be with the power supply switched off.

Argon–hydrogen and argon–nitrogen are used for cutting. Any combination of the gases can be selected at will to suit the material and thickness and the actual ratio of the gases will depend upon the operator. The tungsten electrode may be of 1.6 or 2.0 mm diameter and gives a cut of width about 2.5–3.5 mm with a torch-to-work distance of about 10 mm when cutting with about 250 A (the work is +ve).

Since hydrogen is an explosive gas and nitrogen combines with oxygen of the atmosphere to form the oxides of nitrogen (NO, N_2O, and N_2O_4) in the heat of the arc, cutting should be done in a well-ventilated shop (not enclosed in any way) and protective clothing and the correct eye lens protection always worn, with earmuffs for longer periods.

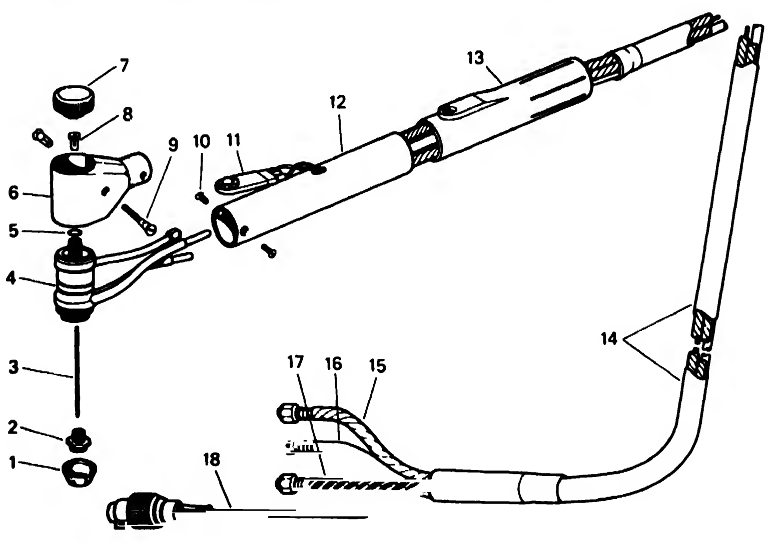
Operation. The unit is switched 'on', current is selected on the potentiometer knob and checked on the ammeter, gases are adjusted for mixture and the torch switch pressed. The pilot arc gas flows and the pilot arc is ignited. The torch is now brought down to about 10 mm from the work (take care not to touch down) and, making sure that all protective clothing including head mask is in order, the torch switch is released and the main arc is transferred to the work. If this does not occur a safety cut-off circuit ensures that the pilot arc current circuit is de-energized after a few seconds.

The arc commences with slow start current and when the thickness of work is pierced, the torch is moved along the plate and if cutting current and speed of travel are correct a steady stream of molten metal flows from the underside of the cut giving a smoothly cut surface. Average currents are in the region of 250 A.

The arc is extinguished automatically at the end of the cut or the torch can be pulled away from the work.

Torch (Fig. 14.14). These can be either hand or machine operated and are supplied with spare electrodes, cutting tips and heat shields. If water-cooled torches of either air or mixed gas are used electrolytic action occurs in the waterways of the torch, due to dissolved minerals in the water. Corrosion occurs and the torch is severely damaged. To prevent this, de-ionized water (about 2 litres per minute) can be used (see p. 688).

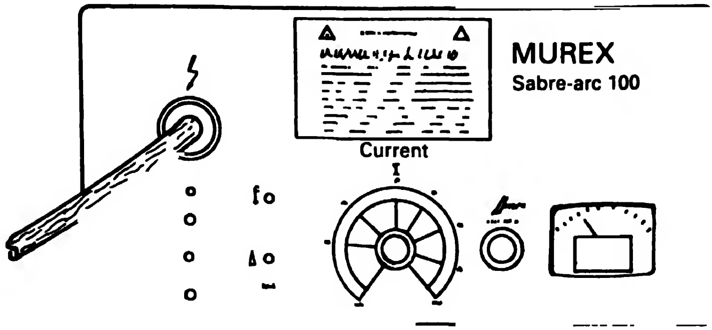
Fig. 14.14. Plasma cutting torch.



Key:

1. Heat shield.
2. Cutting tip.
3. Tungsten electrode 3.2 mm diameter.
4. Torch body.
5. O ring
6. Torch head cover.
7. Torch cap.
8. Collet.
9. Cover retaining nuts and screw.
10. Screw.
11. Torch switch.
12. Handle.
13. Switch boot.
14. Sheath.
15. Main arc cable.
16. Gas hose.
17. Pilot arc cable.
18. Control cable with plug.

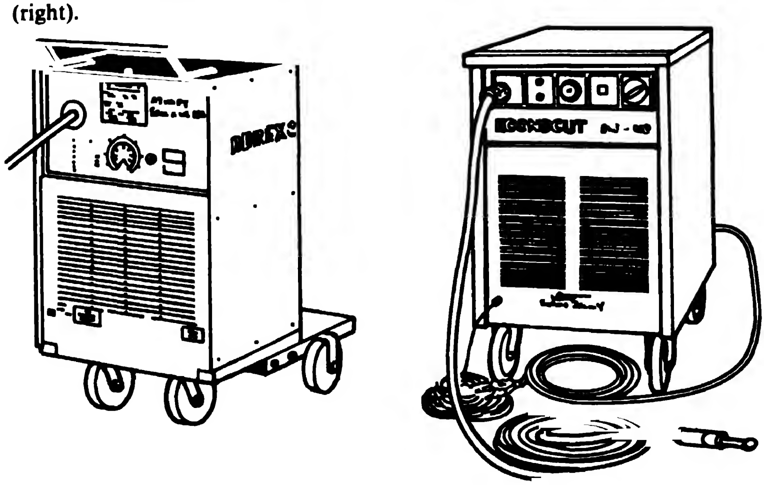
Fig. 14.15. (*a*) Control panel for power unit for air (gas) plasma cutting.



Models available:

Sabre-arc Model	Input V	OCV output	Cutting current	Thickness range mild steel	Rating	Plasma cutting gas	Cooling gas
40i Inverter weight 21 kg	380/415 1(2) phase	200 d.c.	10–40 A	0.5–15 mm	40 A at 60%	Air	Air
100	220/380/ 415	370 d.c.	25–100 A	1–25 mm	100 A at 100%	Air or N_2 or ArH_2	Air or N_2 or CO_2 or O
150	220/380/ 415	370 d.c.	25–150 A	1–37 mm	150 A at 75%	Air or N_2 or ArH_2	Air or N_2 or CO_2 or O_2

Fig. 14.15. (*b*) Sabre-arc unit (left); WTC (Wigan Torch Co.) unit 100–150 A (right).



Air plasma cutting

In this process, instead of using argon, nitrogen and hydrogen as with the tungsten arc, air is used in its compressed form for both plasma gas and cooling. The high plasma temperature provides rapid cutting with little distortion. Sections up to 30–40 mm thick can be cut in steel, low alloy steel, carbon steel, stainless steel, aluminium and bronze. The process is particularly useful for cutting thinner sections. Air contains oxygen, so rapid oxidation takes place within the torch unless steps are taken to reduce it. The tungsten electrode is therefore dispensed with and, instead, electrode and tip are made as small as possible so that they can be discarded when eroded, and are the consumables in this process. The tip has a body of copper into which a small pellet of hafnium wire, with a fine hole down the middle, is pressed centrally in the nose (Fig. 14.16*d*). Hafnium has a lower melting point (2200 °C) than that of tungsten (3400 °C) but it forms a conductive coating with the oxygen which increases its life due to its higher breakdown temperature. An air tube of various sizes controls the amount of air to the tip. The tip fits into the electrode but does touch it (the electrode is the cathode). In addition, as with plasma welding, the work piece, connected to the return cable to the power unit, is also the anode (Fig. 14.16*c*).

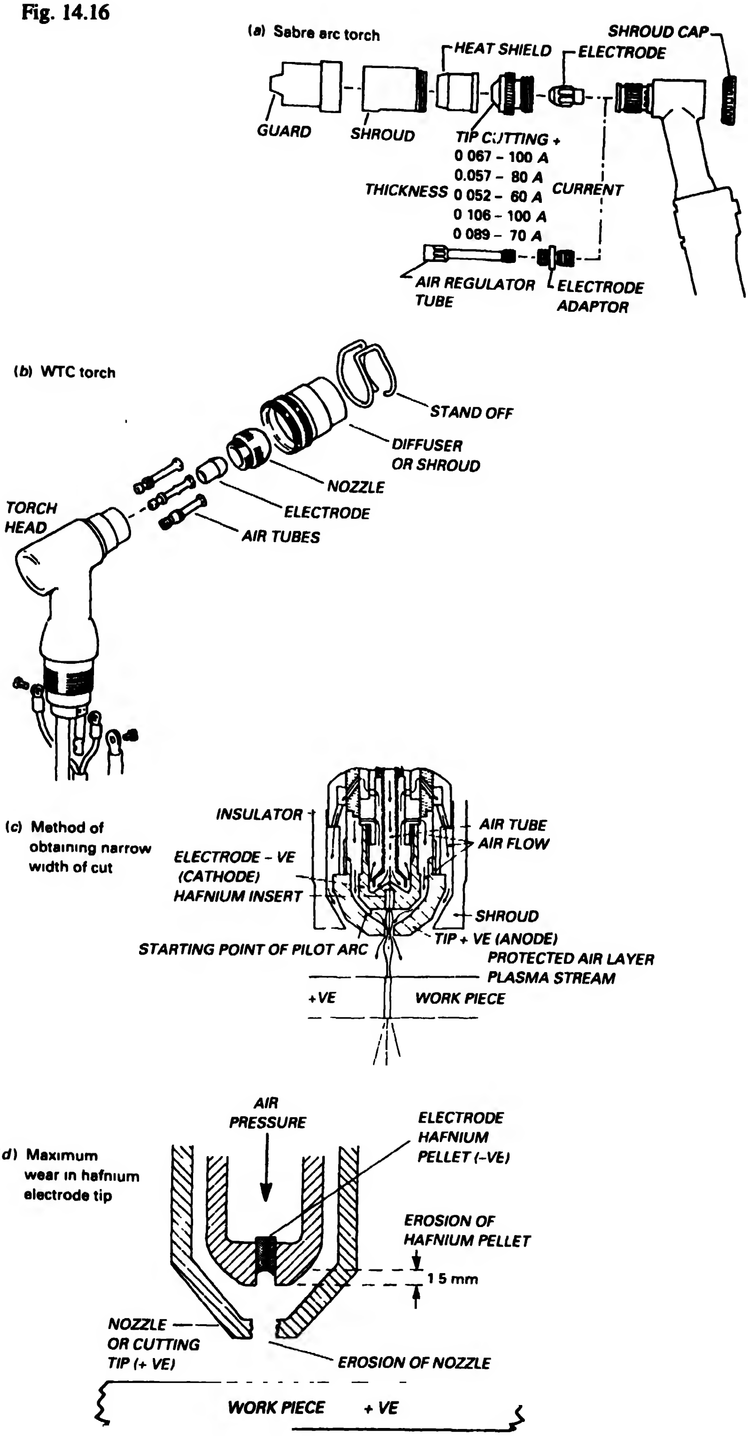
Air is supplied from compressor or cylinders to the torch at a pressure of 5–10 bar and with a volume of about 150 litres per minute. The air must be very finely filtered, dry and free from any oily residues. Of the air fed to the torch head, some passes through the tip and the remainder cools the rear of the tip and, with the rest of the air, circulates through the torch head, cooling it and leaving through a small space between heat shield and diffuser (shroud) (Fig. 14.16). The air which passes through the electrode tip emerges at high velocity to form the plasma stream when ionized.

The power unit is similar to that for gas tungsten cutting (Fig. 14.15). It supplies two electrical circuits. One is supplied at 300 V d.c. open circuit, falling to 100–150 V drop across the plasma when using a current of 20–150 A.

The other circuit is of high frequency (HF) about 4 kV, with a d.c. component of 300 pulses per second. When the switch on the torch handle is pressed, the air gap between tip (nozzle) and electrode breaks down, establishing an arc between them (the pilot arc for ionizing the gap), the air flows through and becomes the plasma stream, for transfer to the cut in the work.

Operation. To operate the unit, the air flow tube, air electrode (jet) and

Fig. 14.16


(a) Sabre arc torch
SHROUD CAP
HEAT SHIELD
ELECTRODE
GUARD
SHROUD
TIP CUTTING +
0 067 - 100 A
0.057 - 80 A
THICKNESS
0 052 - 60 A
0 106 - 100 A
0 089 - 70 A
CURRENT
AIR REGULATOR TUBE
ELECTRODE ADAPTOR
(b) WTC torch
STAND OFF
DIFFUSER OR SHROUD
NOZZLE
ELECTRODE
AIR TUBES
TORCH HEAD
(c) Method of obtaining narrow width of cut
INSULATOR
ELECTRODE - VE (CATHODE)
HAFNIUM INSERT
AIR TUBE
AIR FLOW
SHROUD
TIP + VE (ANODE)
STARTING POINT OF PILOT ARC
PROTECTED AIR LAYER
PLASMA STREAM
+VE
WORK PIECE
(d) Maximum wear in hafnium electrode tip
AIR PRESSURE
ELECTRODE HAFNIUM PELLET (-VE)
EROSION OF HAFNIUM PELLET
1 5 mm
NOZZLE OR CUTTING TIP (+ VE)
EROSION OF NOZZLE
WORK PIECE +VE

tip and the amperage required for the thickness to be cut must be chosen. See that the flow of air is unhindered. The torch head is now brought down and held over the plate to be cut. The switch on the gun handle is pressed, the pilot arc established and the gap ionized. The torch head is now brought down to the correct height, as determined by the stand off guide or guard at the plate edge. The plasma is transferred to the work (it is of positive polarity) and the cut commences. The torch head is moved along so that the cut is smooth and continuous and there is a slight trailing angle as it passes through the metal. At the end of the cut the trigger is released and the plasma extinguished, but the air continues to flow for about a minute in order to cool the torch head. This is controlled by a control circuit in the power unit.

The life of the electrode decreases with increasing current. At 150 A for 40 mm thick plate the life is about 30 min, while at 50 A for 15 mm thick plate the life is about 110 min. In any case the electrode should be changed when the insert has eroded to a depth of about 1.5 mm (Fig. 14.16c). The nozzle or tip has a longer life but should be changed if the orifice is damaged or enlarged. A loss of cutting power may be the result of melting down due to over-use and is accompanied by a green flame.

A ceramic or high-temperature plastic assembly covers the tip (nozzle) to protect it from spatter and a heat shield is often included between tip and shroud. Air passing through the narrow gap between nozzle and diffuser cools the torch head and guides the cooling air into the cut. Attachments, supplied as extras, can be fitted to the torch to give a longer arc for plasma gouging, this method being quieter than the carbon arc method.

Multiple starts cause rapid erosion of the hafnium pellet, and the use of higher currents has the same effect. The higher the current the shorter the life of the tip (nozzle). Remember that tip and electrode are consumables and should be examined constantly for wear. Most complaints about this process are due to trying to operate the tip or electrode (or both) after their efficient life is past.

Examine tip and electrode and replace or clean, if eroded.

De-ionized water

Water taken directly from a tap contains dissolved carbon dioxide (CO_2) with possibly hydrogen sulphide (H_2S) and sulphur dioxide (SO_2) together with mineral salts such as calcium bicarbonate and magnesium sulphate which have dissolved into the water in its passage through various strata in the earth. These minerals separate into ions in the water, for example, magnesium sulphate $MgSO_4$ separates into Mg^{2+} ions (positively

charged) and sulphate ions SO_4^{2-} which are negatively charged. Similarly with calcium bicarbonate ($Ca(HCO_3)_2$) which gives metallic ions, Ca^{2+} and bicarbonate ions HCO_3^{2-}.

By boiling or distilling the water the minerals are not carried over in the steam (the distillate) so that the distilled water is largely free of mineral salts but may contain some dissolved CO_2. Distillation is however rather slow and costly in fuel and a more efficient method of obtaining de-ionized water is now available and uses ion exchange resins. The resins are organic compounds which are insoluble in water. Some resins behave like acids and others behave like alkalis and the two kinds can be mixed without any chemical change taking place.

When water containing dissolved salts is passed through a column containing the resins the metal ions change places with the hydrogen ions of the acidic resin so that the water contains hydrogen ions instead of metallic ions. Similarly the bicarbonate ions are replaced by hydroxyl (OH^-) ions from the alkaline resin. During this exchange insoluble metallic salts of the acid resin are formed and the insoluble alkali resin is slowly converted into insoluble salts of the acids corresponding to the acid radials previously in solution.

The water emerging from the column is thus completely de-ionized and now has a greater resistivity (resistance) than ordinary tap water so that it conducts a current less easily. A meter can be incorporated in the supply of de-ionized water to measure its resistivity (or conductivity) and this will indicate the degree of ionization of the water in the cooling circuit. When the ionization rises above a certain value the resins must be regenerated. This is done by passing hydrochloric acid over the acidic resin, so that the free hydrogen ions in the solution replace the metallic ions (Ca^{2+} and Mg^{2+}). This is followed by passing a strong solution of sodium hydroxide (NaOH) through the column, when the hydroxyl ions displace the sulphate and bicarbonate ions from the alkaline resin.

This process produces de-ionized water, purer than distilled water, easily and quickly.

Water injection plasma cutting

In this process, water is injected through four small-diameter jets tangentially into an annular swirl chamber, concentric with the nozzle, to produce a vortex which rotates in the same direction as the cutting gas (Fig. 14.17). The water velocity is such as to produce a uniform and stable film around the high-temperature plasma stream, constricting it and reducing the possibility of double arcing. Most of the water emerges from the nozzle in a conical jet which helps to cool the work surface.

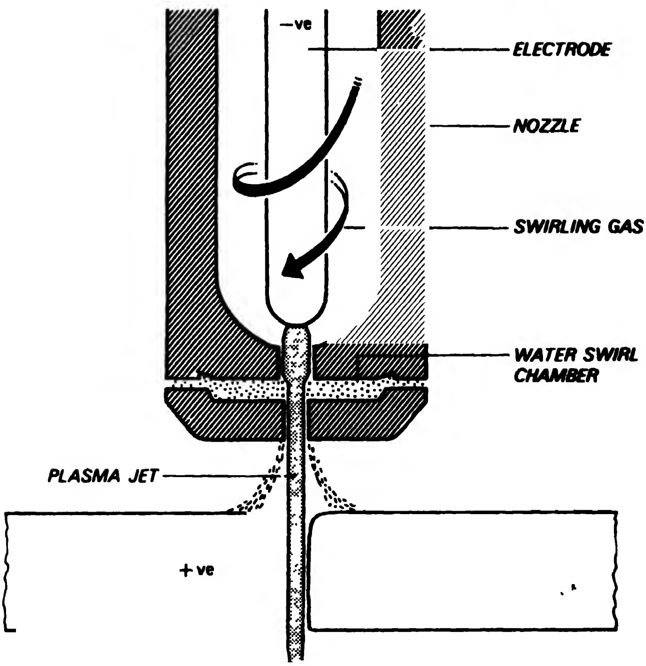
The cut produced is square within about 2° on the right-hand side (viewed in the direction of cutting), whilst the other side is slightly bevelled, caused in general by the clockwise rotation of the cutting gas, which is commercial purity nitrogen. The use of nitrogen reduces cutting costs as it is cheaper than gas mixtures.

The process gives accuracy of cut at high cutting speeds with very smooth cut surfaces. There is little or no adherent dross and the life of the cutting nozzles is greatly increased; mild and carbon steels, alloy and stainless steels, titanium and aluminium are among the metals which can be efficiently cut, in thicknesses from 3 to 75 mm for stainless steel.

The noise and fumes associated with plasma cutting can be reduced by the use of a water muffler fitted to the torch to reduce the noise and by the use of a water table which replaces the normal cutting table and which removes up to 99.5% of the particles and fumes by scrubbing, using the kinetic energy of the hot gases and molten metal stream from the kerf.

This cutting equipment is currently fitted to existing cutting installations up to the largest sizes used in shipyards and including those with numerical control.

Fig. 14.17. The principle of water-injection plasma cutting.



Powder injection cutting

The process of powder injection cutting causes a great deal of fumes to be given off and is one of the less liked operations. As a result it has, in many cases, been superseded by the plasma arc method of cutting of stainless steels, 9% nickel steel and non-ferrous metals. Powder cutting enables stainless steel to be cut, bevelled and profiled with much the same ease and facility as with the oxygen cutting of low-carbon steels.

In cutting low-carbon steels a pre-heating flame raises the temperature of a small area to ignition point. This is the temperature at which oxidation of the iron occurs, and iron oxide is formed when a jet of oxygen is blown on to the area. The heat of chemical combination, together with that of the pre-heating flame enables the oxidation, and hence the cut to continue, the oxide being removed by being blown away by the oxygen jet, resulting in a narrow cut.

For this sequence to occur, the melting point of the oxide formed must be lower than that of the metal being cut. This is the case in low-carbon steel. In the case of stainless steels and non-ferrous metals the oxides formed have a melting point higher than that of the parent metal.

When attempting to cut stainless steel with the ordinary oxy-acetylene equipment the chromium combines with oxygen at high temperature and forms a thin coating of oxide which has a melting point higher than that of the parent steel, and since it is difficult to remove, further oxidation does not occur and the cut cannot continue.

In the powder-cutting process a finely divided iron powder is sprayed by compressed air or nitrogen into the cutting oxygen stream on the line of the cut. The combustion of this iron powder so greatly increases the ambient temperature that the refractory oxides are melted, fluxed, and to a certain extent eroded by the action of the particles of the powder, so that a clean surface is exposed on to which the cutting oxygen impinges and thus the cut continues. The quality of the cut is very little inferior to that of a cut in a low-carbon steel.

Equipment

For hand or machine cutting the powder is delivered to the reaction zone of the cut by means of an attachment fitted to the cutting blowpipe (Fig. 14.18). The attachment consists of powder valve, powder nozzle and tubing. The nozzle is fitted over the standard cutting nozzle and the powder valve is clamped near the gas valves. The iron powder is carried down the outside of the cutting nozzle and after passing through inclined ports, is injected through the heating flame into the cutting stream of

oxygen which it meets at approximately 25 mm below the end of the cutting nozzle.

The nozzle is normally one size larger than for cutting the same thickness of low-carbon steel and is held as for normal cutting except that a clearance of 25 to 35 mm is given between nozzle and plate to be cut to allow the powder to burn in the oxygen stream. The great heat produced makes pre-heating unnecessary on stainless steel and what may be termed a 'flying start' can be made.

The powder dispenser unit (Fig. 14.19) is of the injector type and is a pressure vessel which incorporates:

(1) A hopper for filling.
(2) An air filter.
(3) An air pressure regulator.
(4) A dryer.
(5) An injector unit.

The removable cover enables the hopper to be filled and is fitted with a pressure relief valve which lifts at 0.15 N/mm². A screen for removing over-large particles from the powder and a tray for the drying agent are fitted.

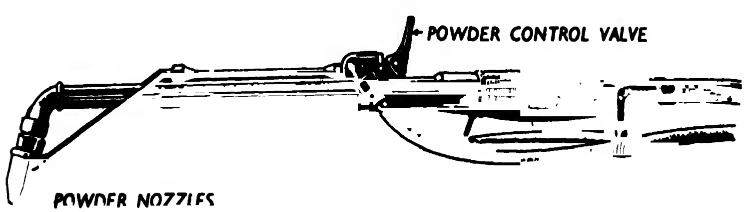
Compressed air flows into the dispenser, picks up powder and carries it along a rubber hose to the cutting nozzle. Nitrogen may be used instead of air but never use oxygen, as it is dangerous to do so. The powder flow from the dispenser is regulated by adjusting the nozzle or by varying the air pressure.

The dispenser should be fed from an air supply of 1.5 m³ per hour at a pressure of 0.3 N/mm². The usual pressure for operating is from 0.02 to 0.03 N/mm².

Since the whole process depends upon a uniform and smooth flow of powder every care must be taken to ensure this. Any moisture in either the powder or in the compressed air can cause erratic operation and affect the quality of the cut.

Silica gel (a drying agent) is incorporated in the dispenser to dry the powder but the amount is not sufficient to dry out the compressed air and a

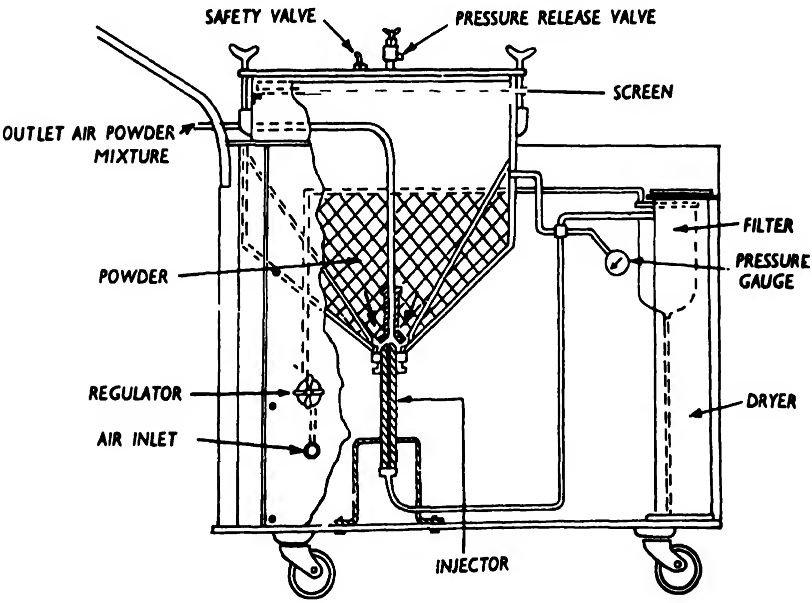
Fig. 14.18. Cutter equipped for powder cutting.



separate drying and filtering unit should be installed in the air line to ensure dry, clean air. The oxygen and acetylene is supplied through not less than 9 mm bore hose with 6 mm bore for the powder supply.

The single-tube attachment discharges a single stream of powder into the cutting oxygen and is used for straight line machine cutting of stainless steel. The multi-jet type (Fig. 14.18) has a nozzle adaptor which fits over a standard cutting nozzle and has a ring of ports encircling it. The powder is fed through these ports and passes through the heating flame into the cutting oxygen. This type is recommended for hand cutting and for profile, straight and bevel machine cutting. Special cutting nozzles are available for this process. These give a high velocity parallel cutting oxygen stream from their bore being convergent–divergent. The pre-heater holes are smaller in number but more numerous and are set closer to the cutting oxygen orifice than in the standard nozzle. This gives a soft narrow pre-heating flame, giving a narrower cut and better finish with a faster cutting speed. Since the iron powder is very abrasive, wear occurs in ports and passages through which the powder passes. By using stainless tube where possible, avoiding sharp internal bends and reinforcing certain parts, wear is reduced to a minimum.

Fig. 14.19. Powder dispenser unit.



Technique

In cutting any metal by this process, correct dispenser setting, dry air and powder, clean powder passages and leak-tight joints all help towards ensuring a good quality cut. The rate of powder flow is first adjusted to the correct amount for the particular work in hand by trial cuts.

Stainless steel. Size of nozzle is one size larger than for the same thickness low-carbon steel. For thicknesses up to 75 or 100 mm the nozzle is held about 25 mm from the plate, for thicknesses up to 150 mm the distance is increased to about 35 mm, while for heavier sections it can be about 50 mm distant. No pre-heating is necessary – an immediate or flying start can be made. Scrap plate may be loosely put together and a single cut can be made, the great heat enabling this to be done in spite of gap between the plates.

Cast iron and high-alloy steels. Technique for cast iron is similar to that for stainless steel but cutting speed is up to 50% slower. With high-alloy steels for example, a 25/20 nickel–chrome steel takes 30–40% longer than for the 18/8 nickel–chrome steel. Pre-heating of high-alloy tool steels is advisable to prevent risk of cracking due to localized heat.

Round carbon steel bars are easily cut by laying them side by side. The cut is done from bar to bar, powder being switched on to start the cut on each bar giving no interruption in cut from bar to bar.

Nickel and nickel alloys. Pure nickel is extremely difficult to cut because it does not readily oxidize and it can only be cut at slow speed in thicknesses up to 25 mm section, whereas INCONEL® and NIMONIC® alloys can be cut up to 125 mm thick, speeds being up to 60% slower than for the same thickness of stainless steel.

Copper and copper alloys. In this operation copper is melted (and not cut) the particles of iron powder removing the molten metal and eroding the cut.

Much pre-heating is required due to the high conductivity of copper and copper alloys – for example – a powder cutting blowpipe capable of cutting 180 mm thick stainless steel can only deal with copper up to 25 mm thick and brass and bronze up to 100 mm thick. A lower cutting oxygen pressure than normal is used and the nozzle moved in a forwards, upwards, backwards, downwards motion in the line of the cut, thus helping to remove the molten metal and avoiding cold spots.

Aluminium and aluminium alloys. The quality of the cut is poor and of ragged profile. Alloys containing magnesium such as MG7 develop a hard surface to the cut due to formation of oxide and this may extend to a depth

of 16 mm. As a result powder cutting is limited to scrap recovery. Cutting (or melting) speeds on thinner sections are much the same as for stainless steel, but with thicker sections molten metal chokes the cut, so that large nozzles with reduced cutting oxygen pressures should be used.

Powder cutting can be incorporated on cutting machines and gouging can be carried out as with the normal blowpipe with the same ease and speed, the nozzle being again held further away from the work, to allow space for the combustion of the powder.

Underwater cutting

Underwater cutting of steel and non ferrous metals is carried out on the oxy-arc principle using the standard type of electrode which has a small hole down its centre through which the pressurized oxygen flows to make the cut. By using a thermic electrode, this oxygen stream causes intense oxidation of the material of the electrode, giving a greatly increased quantity of heat for the cut. In both cases the products of the cut are removed or blown away by the oxygen stream.

A d.c. generator is used with the torch negative and the special type earth connexion, connected to clean, non-rusted metal in good electrical contact with the cut, is positive polarity: a.c. is not suitable as there is increased danger of electric shock.

The torch head for ordinary or thermic electrodes is similar. It is tough rubber covered and has connections for oxygen and electric current. The electrodes, usually of 4 mm ($\frac{5}{32}''$) and 4.8 mm ($\frac{3}{16}''$) diameter are securely clamped in the head by a collet for the size electrode being used. A twist of the torch grip clamps and releases the collet and is used for stub ejection. These collets can be changed to allow the torch head to be used for welding (Fig. 12.23).

The oxygen cylinder, fed from a manifold, has a high volume regulator which will give free flow and pressures from 8 bar (118 psi) at 12 m depth to 20 bar (285 psi) at 107 m. In general the oxygen supply to the torch should give about 6 bar (90 psi) over the bottom pressure at the electrode tip.

Ingress of water to the torch head is prevented by suitable valves and washers and replaceable flash arrester cartridge and screen are fitted.

The seal for the electrode in the torch head is made with washers and collet and tightened in place with the torch head locknut. When the electrode is fitted to the head it must bottom on to the washer and be held tight to prevent leakage of oxygen. Note that the thermic type of electrode will continue burning once it has been ignited, even when the electrical supply is switched off, due to the oxidizing action of the gas stream.

Use of equipment

An eyeshield with the correct lens fitted is attached to the outside of the diver's helmet. No oil nor grease should be used on the equipment and there should be no combustible nor explosive materials near to the point where cutting (or welding) is to be performed. Hose connexions should be checked for leaks and all electrical connexions tight, especially check the earth connexion and see that it is in good electrical connexion with the position of the cut. As electrolysis can cause rapid deterioration, all equipment should be continually inspected for signs of this. If any part of the work is above water level, connect the earth clamp to this after checking that there is a good return path from the cut to the earth clamp.

A double pole single throw switch of about 400 A capacity is connected in the main generator circuit as a safety switch. This should always be kept in the 'off' position except when the cut is actually taking place. To begin cutting, strike the arc and open the oxygen valve by pressing the lever on the torch.

When working, the diver-welder must always face the earth connexion so that the cutting is done *between* the diver and the earth connexion. When the electrode has burnt to a stub of about 75 mm in length the diver should call to the surface to shut off the current by opening the safety switch. This having been done the collet is loosened by a twist of the wrist, the oxygen lever is pressed and the stub is blown out of the holder. A new electrode is now fitted, making sure that it sits firmly against the sealing washer, and the handle twisted to lock it in place. Stubs should not be burnt close to the holder for fear of damage. When the safety switch is again placed in the 'on' position cutting can again commence.

When cutting, bear down on the torch so as to keep the cutting electrode against the work so that the electrode tip is in the molten pool and proceed with the cut as fast as possible consistent with good cutting. Spray back from the cut indicates that it is not through the work completely. Keep all cables and hoses from underfoot and where anything may fall on them. Pipes and tubes may be cut accurately to size under water by a hydraulically operated milling machine which is driven around a circumferential guide.

Safety precautions

The general safety precautions which should be observed when welding are listed at the end of the section on oxy-acetylene welding but special precautions should be taken when cutting processes using oxygen are used in the welding shop or confined spaces. Oxygen is present in the atmosphere at about 29.9% by volume and below 6–7% life cannot be sustained.

In Appendix 11 on fire precautions we state that for a fire to occur we need (1) oxygen, (2) fuel and (3) heat.

Oxygen rapidly oxidizes combustible materials and in the case of grease or oil the oxidation reaction produces so much heat that the material may be ignited, thus causing fire or explosion. When cutting with the oxy-acetylene or oxy-propane flame the oxygen (cutting) lever should not be kept open longer than necessary because not only is the compressed gas expensive but it also causes oxygen enrichment of the atmosphere in confined spaces. Should the operator be wearing gloves and clothing that are greasy or oily, the oxidation of this grease and oil may cause burning with evolvement of heat so that the operator may sustain burns and a fire or explosion may endanger life.

Never use compressed oxygen for any other purpose (e.g. in place of compressed air) other than cutting (or welding). Make sure that the ventilation of the area is good – cutting in confined spaces always presents a hazard. Oil, grease and other combustible material should never be in the vicinity where cutting is taking place.

Since oxygen has no smell or taste its presence is difficult to detect and no smoking should be allowed in areas where oxygen is being used.

15

The welding of plastics

Plastics

Plastics are replacing steel and other metals used in construction. They are now used in the home, in gas engineering, farming, sports equipment, and in the automobile industry etc. Equipment made of plastic is lighter than that made of steel, and since welding and fabrication is relatively easy and the cost of repair lower, it will be well to consider some of the processes involved.

Plastics are derived mainly from oil, coal and wood. Polystyrene and polyvinylchloride (PVC) are examples of those derived from oil and coal while the cellulose types (such as cellulose acetate and ethylcellulose) are produced from wood. Plastics consist of larger molecules built up into chains arranged randomly, from single molecules (monomers) by a process of polymerization, assisted by a catalyst. (A catalyst is a substance that accelerates a chemical reaction but undergoes no permanent change during the reaction.) If differing monomers are used, copolymers are produced from which the characteristics of the original monomers cannot be obtained.

There are two main types of plastic: (1) thermo-setting and (2) thermoplastic. A thermo-setting plastic is one that softens when first heated and is then moulded into the required form. Upon cooling it sets hard and gains its full strength. Upon reheating it does not again soften and thus cannot be reshaped. An example of a thermo-setting plastic is that made from phenol and formaldehyde, which with an acid catalyst gives a soluble and fusible resin used in varnishes, and with an alkaline catalyst gives an infusible and insoluble resin (Bakelite).

Thermoplastic substances soften each time they are heated and can be reshaped again and again, regaining their rigidity and strength each time

upon cooling. Foil, thin and thicker sections, fabrications, repairs to automobile components and welding in general, can be successfully carried out on thermoplastics.

Welding may be by: (1) external heating, i.e. hot air, hot plate, resistance and RF processes; (2) external movement, i.e. friction or spin, ultra-sonic and other vibrations (100–240 Hz); (3) adhesive, i.e. cyano-acrylates (super-glue). Method (1) is of the most interest to the welder, and hot air and hot plate will be considered in detail.

Table 1 gives the thermoplastics most commonly used for fabrication and in repair work, while Table 2 indicates tests which may be carried out to identify a plastic by removing a shaving from it and burning it in a low flame, carefully observing the results. It is essential that rod and parent plastic should be compatible. To ensure this the makers of plastic welding equipment supply small bundles of various rods as given in Table 1. Tests are carried out on the given plastic with each of the rods until one is found that fuses well and easily into the parent plastic. Compatibility of rod and plate cannot be stressed enough. Note, however, that flame or burn tests

Table 1. *Types of plastic suitable for welding*

Identification	Plastic	Welding temperature (°C)
ABS and ABS/PC	Acrylonitrile-butadiene-styrene and ABS/polycarbonate	350
PVC high density	Polyvinylchloride hard	300
PVC low density	Polyvinylchloride soft	400–500
PC	Polycarbonate and polycarbonate modified	350
PE high density (HDPE)	Polyethylene high density	300
PE soft density (SDPE) (polythene)	Polyethylene soft density	270
PP	Polypropylene	300
PA	Polyamide	400
PP/EPDE	Polypropylene 3-ethylene-diene rubber	300
PUR (polymer alloy)	Polyurethene (not all types are weldable)	300–350
PBT	Polybutylene tetraphthalate	350
Acrylics (e.g. PMMA)	Resins. Usually transparent, e.g. polymethyl methacrylate	350

Note. Glass-reinforced plastics are not generally weldable and foam-filled PU should not be welded.

are little used nowadays because of the difficulty in differentiating between plastics with the same burning characteristics.

Welding thin sheets

Thin sheets are welded by applying heat and pressure to the joint. The sheets are overlapped and then passed between two rollers; the width of roller determines the width of the weld. One of the rollers is motor driven and can be heated by an electrical element. The other roller is free rolling and serves only as a back pressure for the heated roller. The variables are therefore: (1) the temperature of the heated roller, (2) the speed at which the surfaces to be welded pass between the rollers, and (3) the pressure between the rollers. The two surfaces to be welded together pass when in the spongy state – just below melting. The heating element for the main roller has a potentiometer control and the element conducts its heat to the roller. To operate, the temperature is selected for the given plastic (e.g. PVC), for which welding temperature is 300–500 °C. The motor is set at the correct speed to rotate the driven roller, and finally the pressure between the rollers is set. If the current is too low (temperature), or the pressure and speed of travel between the rollers too high, the two sheets will not weld together. If the current is too high and the speed of travel too low, the sheets will be welded together only in certain parts and holes will appear. It will be appreciated that the three variables are notoriously difficult to adjust correctly. Modern machines greatly simplify this procedure. Note that the process is similar in many ways to seam welding (p. 550). If the roller is hand-operated (usually for simple welds only) a smooth surface, under the part to be welded, is fixed so that it takes the place of the bottom roller (Fig. 15.1*a*). Again the temperature of the heating element is set and the roller unit moved down the seam with a medium pressure. As before, if the speed is too high the sheets will not

Table 2. *Tests for identification of plastics*

Plastic	Observations
ABS	Sweet smell; burns with a black sooty flame not self-extinguishing
PC	Burns with black sooty smoke; not reliably self-extinguishing
PE	Smelly and feels like a wax; burns like a wax candle and drips
PP	Similar to PE; feels like wax and smells and drips like wax
PA	Smells like burnt horn; flame not self-extinguishing; stringy
ABS/PC	Sweet smell; black sooty smoke; flame not self-extinguishing
PVC	Burns with black smoke and an acrid smell; not self-extinguishing

be welded together, while too slow a speed results in an unsatisfactory weld with holes down the length of it. The weld must be mechanically sound and continuous. Fig. 15.1(*b*) shows a taped seam welded with hot air from a gun.

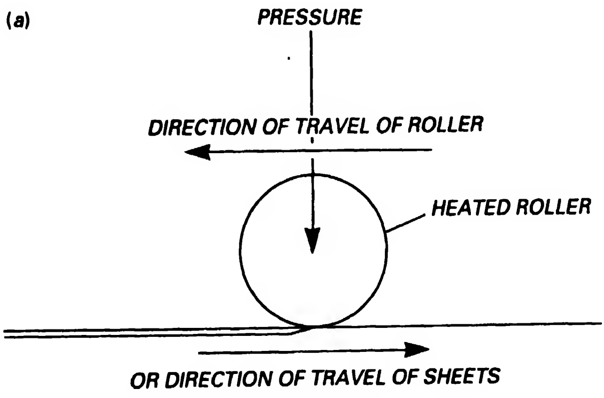
Hot air (or gas) welding

Guns or torches. The guns for this method of welding operate on the same principle as a hair dryer, in which a stream of air, propelled by a fan driven by an electric motor, flows over a heated electric element. They are available in various voltages and power loadings: 200–240 V, 1500 W, or 110–120 V, 1700 W and lower voltages if required. Hot gas guns were originally supplied with compressed carbon dioxide or nitrogen but most of them use air nowadays, although the term hot air gun includes hot gas guns.

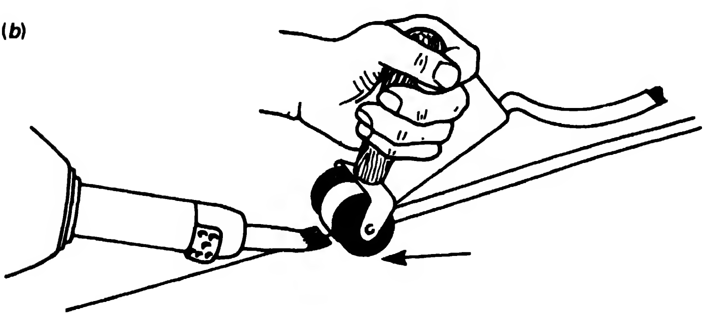
Some guns have an electric motor in the body of the gun, from which

Fig. 15.1. (*a*) Sheet welding. (*b*) Welding of taped seam with hot air and pressure.

(*a*)



(*b*)



the air is supplied, while others use air supplied from an external compressor. In the latter, there are two leads to the gun: the electricity supply for the heating element and the compressed air supply. This type of gun is lighter and of smaller diameter than the type with an electric motor in the body. However, the gun with the motor has the advantage that there is only one cable feeding the motor and element (Fig. 15.2). In both types the air is blown over an electric element, the temperature being accurately controlled (by potentiometer). There is a switch on the outside of the body of the gun, clearly marked so that any temperature between 300 °C and 600–700 °C can be selected for the air issuing from the gun. In some guns the heating element is easily replaceable. The volume of air passing over the element is controlled by a movable shutter over the air intake. The gun barrel gets very hot during use and should on no account be touched. Some guns have an outer shield over the barrel to prevent it being touched accidentally.

Nozzles. A variety of nozzles are available, all having either a tight push-on fit, locked on with a clamp ring and screw, or a screwed-on fit. These

Fig. 15.2. (*a*) Hot air torches for general use.

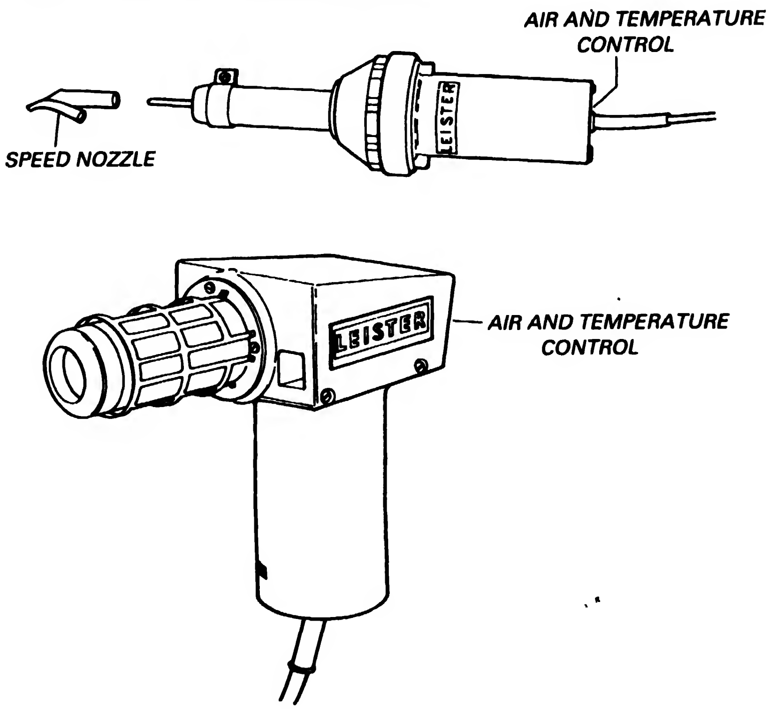


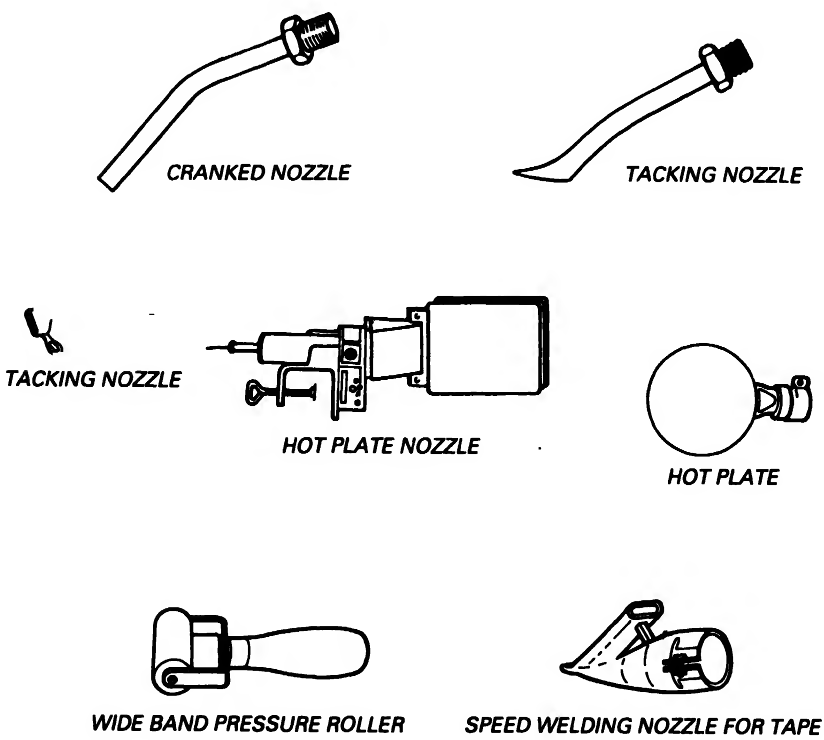
Fig. 15.2. (*b*) High speed torch or gun showing relative size (Goodburn).

nozzles are obtainable with diameters 3 mm, 4 mm and 5 mm I/D. The following are the most important.

The tack welding nozzle has an open mouth for the hot air, and there is a blunt toe on its front or toe end (Fig. 15.3). The sheets to be welded are close butted together, the hot air from the gun softens the edges of the sheets for the preparation to welding condition and the blunt toe draws the edges together as the gun moves along the surfaces, with the angle of the base of the nozzle about 15–30° to the seam of the joint. The tack weld has little strength and should not be subjected to any load. It is for positioning only and to ensure fusion at the bottom of the weld.

The speed welding nozzle (Fig. 15.4) consists of two tubes – either round or triangular – joined at the bottom end. One tube is for hot air and the other for the rod (round, triangular (profiled) or tape as required). The unit is pushed or screwed onto the gun. The hot air tube has a small-diameter tube inside it down which the hot air passes. At the bottom end is a baffle plate with a 3 mm hole in it, and the bottom of the hot air tube finishes about 20 mm from the baffle so that during welding some of the

Fig. 15.3. Types of nozzle.



air passes through the baffle hole and preheats the joint, while the rest of the hot air is available for the welding operation, enveloping the base of the rod and the edges of the preparation. The rod to be used is passed down the other tube in which it should be an easy sliding fit.

The rod is preheated by the tube, and a shoe on the front of the nozzle rests on the completed weld. There is also a speed welding nozzle with no baffle plate and a simple mixing chamber at the base. Speed welding is dealt with in detail later. Some units have a swing back tacking unit to save time when changing nozzles. There are special high speed nozzles for left-hand and right-hand welding in tight corners, and tank openings etc. Nozzles are available for 3, 4, 4.5, 5 and 6 mm round, 4 × 4 × 4 mm,

Fig. 15.4. Speed welding nozzles.

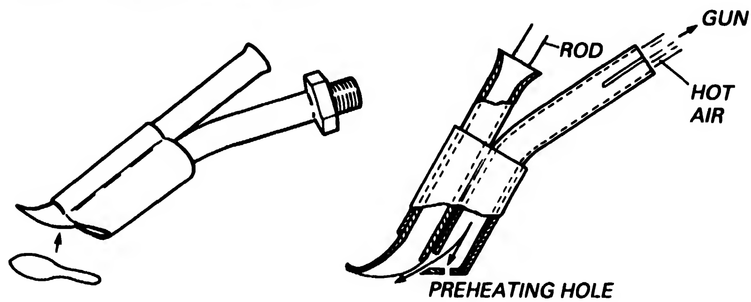
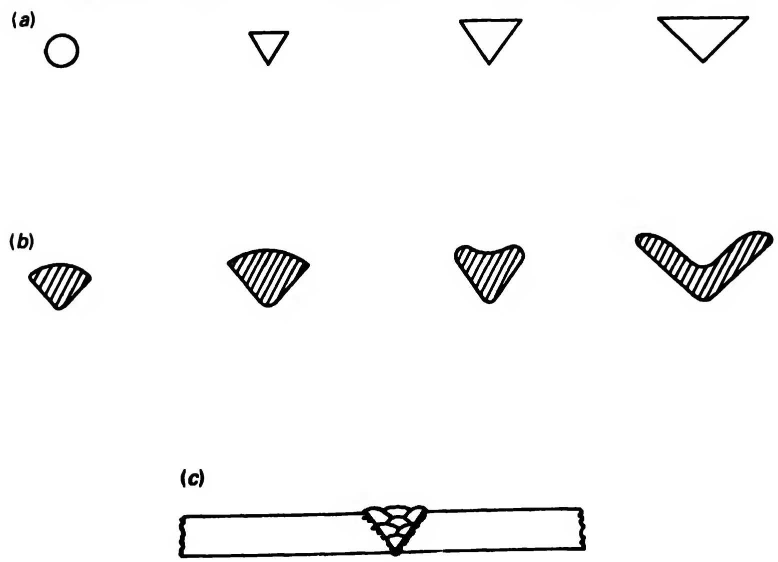


Fig. 15.5. (*a*) Sections of welding rod. (*b*) Profiled welding rods. (*c*) Multi-run.

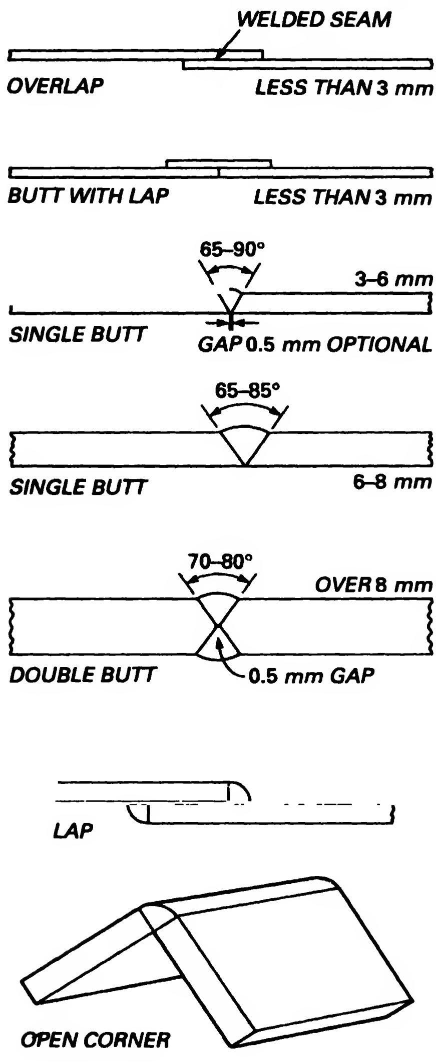


5 × 5 × 5 mm, 6 × 6 × 6 mm triangular rods, and sections for special use such as 5 × 5 × 4 mm, 6 × 4 × 4 mm profiled (see Fig. 15.5).

Preparation

Sheets up to 3 mm thickness require no preparation. They can be butted together and a tape of the same material and about 20–40 mm wide welded along the seam (Fig. 15.1*b*). This is followed immediately by using a hand-pressed roller to complete the operation. Very thin sheets of

Fig. 15.6. Types of joint and preparations.



PVC or polythene can be welded together by a heated wheel and hand pressure along the seam, or automatically in a machine which heats the roller and supplies pressure and movement.

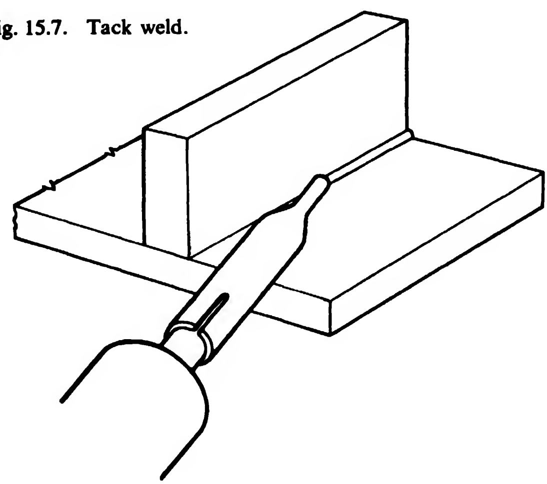
When hand welding, sections up to 6 mm thick can be prepared with a 65–90° V, while sections of greater thickness can have either a single V of 65–85° or a double V of 70–80° (see Fig. 15.6). If the tack welding nozzle is used there is no need to allow any gap between sections.

If cracks are to be welded up in, for example, a car spoiler or bumper, they should be carefully inspected and a small hole, say 2 mm diameter, drilled at each end of the crack to prevent it travelling any further during welding. The plastic to be welded is then identified if possible, and a suitable rod selected. If identification is not possible, one rod at a time is selected from a bundle of rods of varying types, supplied by the manufacturers, until a rod is found that will fuse very well with the parent plate when heat is applied. It is essential to have rod and parent plate 'compatible' so that fusion results in a sound bond. In each case the temperature of the hot air to be used is selected on the gun.

Tack welding

The parts to be welded are placed in position and lined up. The gun, with tack welding nozzle on, is allowed about 2 minutes to heat up, and the front or toe of the nozzle is placed on the bottom of the commencement of the seam to be welded. The nozzle is held in this position until the sides of the weld begin to sweat and the gun is kept at an angle of about 30–40° to the seam and drawn along the seam bringing the two sides together and the tack weld is completed (Fig. 15.7). When cool, the tacking nozzle is exchanged for a straight or cranked standard nozzle.

Fig. 15.7. Tack weld.

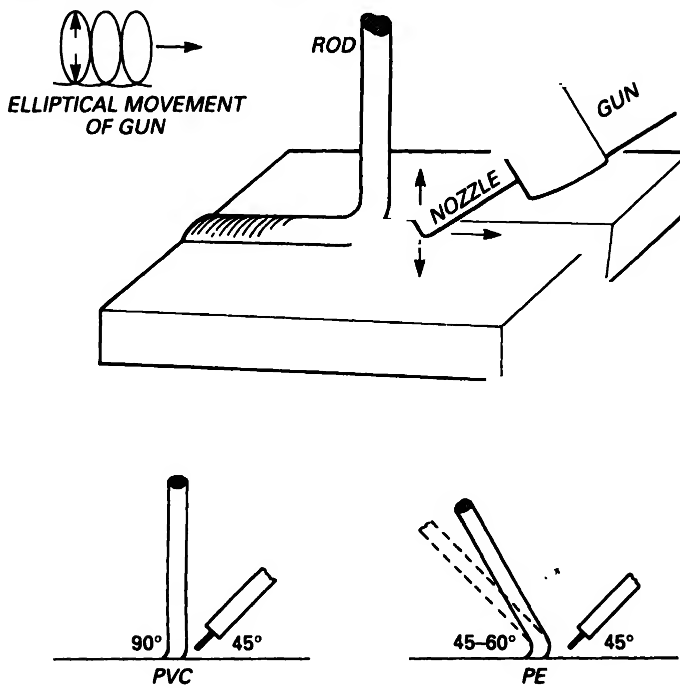


General welding

The rod is held at right angles to the weld at its commencement and hot air from the gun is played on the bottom of the rod and the parent plate until the rod begins to melt, spongily, into the prepared joint. The gun is held at an angle of about 45° to the seam, and moved up and down pendulum fashion with an amplitude of about 20–30 mm and a slight elliptical bias, as shown in Fig. 15.8. As the weld progresses down the seam with the gun preceding the rod, there should be a slight hesitation at the bottom of the stroke to ensure good fusion with the parent plastic. The rod softens and flows easily into the prepared groove with a minimum of hand pressure, say 1.5–2.5 kg. Any sudden reduction of pressure (e.g. when changing position of the fingers on the rod) may cause the rod to lift from the weld and, by trapping air, weaken the weld.

The rod angle is 90° to the weld for PVC, but for polypropylene and polyethylene the rod angle should be 45–60° in order to exert sufficient downward pressure on the rod. A reduced angle for PVC may produce cracks in the finished weld on cooling. To finish a weld, rod movement is stopped and heat applied to where the rod meets the parent plastic. The heat is then removed, keeping a downward pressure on the rod. The rod

Fig. 15.8. Down hand butt weld.



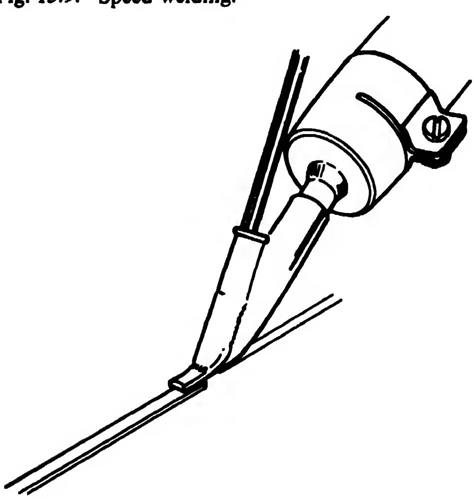
is then allowed to cool and is twisted off. Continuation of a weld can be performed by cutting the weld where it finishes at an angle of about 30° and starting the new weld at this point.

If a weld is to be made right around a pipe, the finish of the weld should overlap the beginning of the weld by about 10–15 mm and not finish alongside it. Using a wide slot nozzle, a tape welded seam can be made to fasten two sheets of plastic butted together. (See section on machine welding.)

Speed welding

The speed welding nozzle, as already described, is fitted to the gun. The welding rod or coil is prepared by sharpening one end to a pencil or chisel point. It is then pushed into the feed tube on the nozzle (and must be an easy sliding fit) until about 2.5–3.5 mm protrudes from the end. The tube on the nozzle is obtainable in various types of section, corresponding to the available rods (see Fig. 15.5). The gun is now held vertically at a point about 65–85 mm above the surface, thus preheating it. The gun, still held vertically, is brought to the commencement of the weld and the sharp end of the rod pushed in so that the sharpened end projects beyond the start of the weld at the front of the nozzle. Hand pressure is kept on the rod at the start, in order to obtain good fusion. When rod and parent plastic are completely softened and the rod begins to fuse into the plastic, the weld commences and the angle of the gun is lowered to about 45° to the line of weld. It is then drawn slowly down the weld preparation, the rod needing little or no feeding and only slight guidance. Remember that

Fig. 15.9. Speed welding.



the angle between the gun and the weld determines the rate of welding, since the preheat hole varies the amount of preheat (Fig. 15.4). When the welding rate is too slow there are charred edges to the weld (PVC), when the rate is too high, there is incomplete fusion with no flow lines. The completed weld should be smooth with a faint wash visible down each side, an indication of good fusion of rod and parent plastic (Fig. 15.9). Note that if cracks are being repaired they should be welded in a continuous run, with, if possible, no stopping. To terminate a weld the gun is brought to the near vertical position and the rod is cut off by slipping the nozzle off the rod, leaving it standing attached to the weld. When cool it can be cut off close to the weld. If multi-layers are required (Fig. 15.5) each run should be allowed to cool before the next is applied. Since thermoplastics are poor conductors of heat, the stresses that arise during welding are concentrated in a smaller area than when welding metals. When welding V-prepared joints, the use of a profile rod and the process of speed welding reduces the stresses and accompanying strains. Note that the expansion coefficient of plastics is many times greater than that of steel.

Practical hints

At first, speed welding appears more difficult than that with an ordinary nozzle, because of the difficulty in obtaining penetration of the weld when starting. The first attempts result in no penetration until the weld has started to be made. It is difficult to heat both rod and plate (keeping some pressure on the rod) until the plate is hot enough to begin the operation. If the welder is too slow, the welding rod in the tube feeding the weld (which is fairly spongy due to preheating in the tube) quickly becomes charred, and the tube becomes blocked by the charred rod. It must then be cleared by pushing a steel rod of just smaller diameter than the tube through it. To overcome this the plates to be welded are preheated with the gun held vertically and then the pointed rod is immediately pushed quickly down the tube and the end guided under the shoe of the nozzle. The gun is held in this position until the rod melts into the parent plate; the angle of the gun is quickly reduced to about 45° and the weld commences immediately and must not stop, the rod being fed automatically by the welding operation and only guided by the fingers. If it is a longer weld, the coil of welding rod can be slipped over the welder's arm onto the shoulder whence it feeds itself automatically into the weld. If difficulty is met in starting the weld, use a small run on plate until the desired time for a good start is found. Keep the underside of the nozzle clean with a wire brush.

Machine (tractor) welding

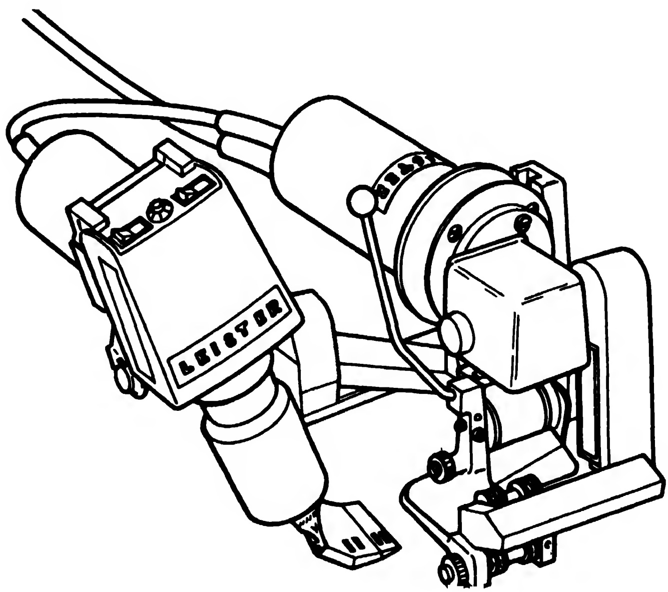
Long seams in plastic sheets (e.g. PVC and polythene) can be welded together by moving a hot air gun suitably mounted and driven by an electrically driven tractor; for ease of replacement the heating element is of the plug-in type (Fig. 15.10).

The sheets may be butted together and a tape of the same material as the sheet and about 20–50 mm wide placed across the length of the joint and the tape welded to the butted seam, followed, where required, by a roller which presses the tape tightly to the seam. The machine is available as 220–240 V, 4.2 kW and 380–400 V, 5.2 kW, with other voltage ranges and loadings for various models. The machines are available for tilt welding (welding on roofs) and the speed is infinitely adjustable between set ranges, e.g. 1–3, 1–6 and 1–12 m/min as required.

The second method much used is overlap welding. The plastic sheets are overlapped up to 100 mm and sand or other material is placed beneath, so as to give a firm underside and one that will not damage the welding process. A test channel may be included, so that the joint can be tested from 2 to 5 bar for any leaks, which can be sealed by hand operation.

With the correct temperature selected and the correct speed of travel

Fig. 15.10. Leister hot air automatic welding machine for overlap welding of thermoplastic film.



the machine produces an excellent weld between the sheets using a wide slot nozzle. For thin plastic sheets (e.g. bags) welding can be performed by a hand or machine driven roller. In both cases speed and temperature must be absolutely correct. Using a hand-held automatic welder, vertical and overhead seams about 10 mm thick can be tape welded and a test channel incorporated.

High frequency spark testing

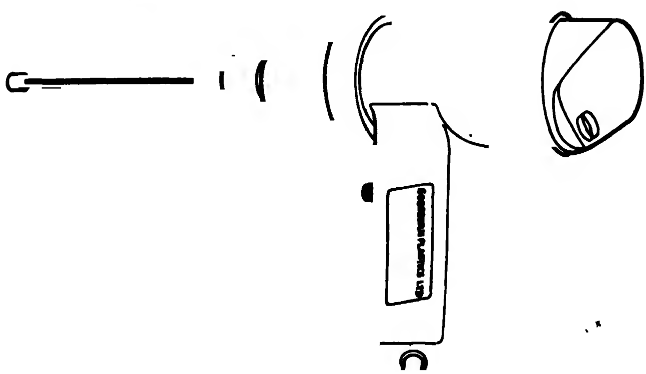
Among the many uses of the high frequency spark tester is the testing of welded joints for porosity and, where required, the testing of the parent plastic for the same defect.

The spark tester is in the form of a light weight gun (Fig. 15.11), and is made for 100–125 V or 220–250 V supply, the loading being only 30 W so that it can be used from any 3-pin socket. The testing voltage is 55 kV maximum and the frequency 200 kHz.

Operation

There is a voltage control on the spark gun, which is important since any sheet or dielectric will break down if the applied voltage is too high. There is a probe fitted to the gun, onto which the high voltage is applied; the probe is then brought near an earthed metal plate and the trigger pressed. The sparks which emanate from the probe are adjusted in length until they are just a little longer than the thickness of the plastic and weld to be tested. The thinner the plastic, the smaller the voltage that

Fig. 15.11. High frequency spark gun (Goodburn).



must be applied, because too high a voltage puts greater strain on the plastic (the dielectric).

The plastic weld under test is placed on the earthed metal plate and the gun switched on. The probe is then moved over the surface of the joint or other surface under test. When any defect is passed over, there is a bright spark and a hissing sound. The position of the defect is marked and the remainder tested as before. The defects are then repaired and the tester again moved over the positions of the faults to ensure that they have been correctly repaired. All plastics including nylon can be tested for plate or weld porosity using the probe from the gun, the material to be tested lying on the earthed metal plate.

Hot plate (or hot iron) welding

The parts of, say, polyethylene or PVC should have uniform profiles and diameters (e.g. pipes). The ends are prepared with a pipe-cutting tool and are lined up with one another using a jig. The ends are then lightly cleaned, kept separated and not touched. The hot plate, which may be of nickel-plated steel or aluminium, for example, is placed between the ends to be welded and the parts moved up to the plate.

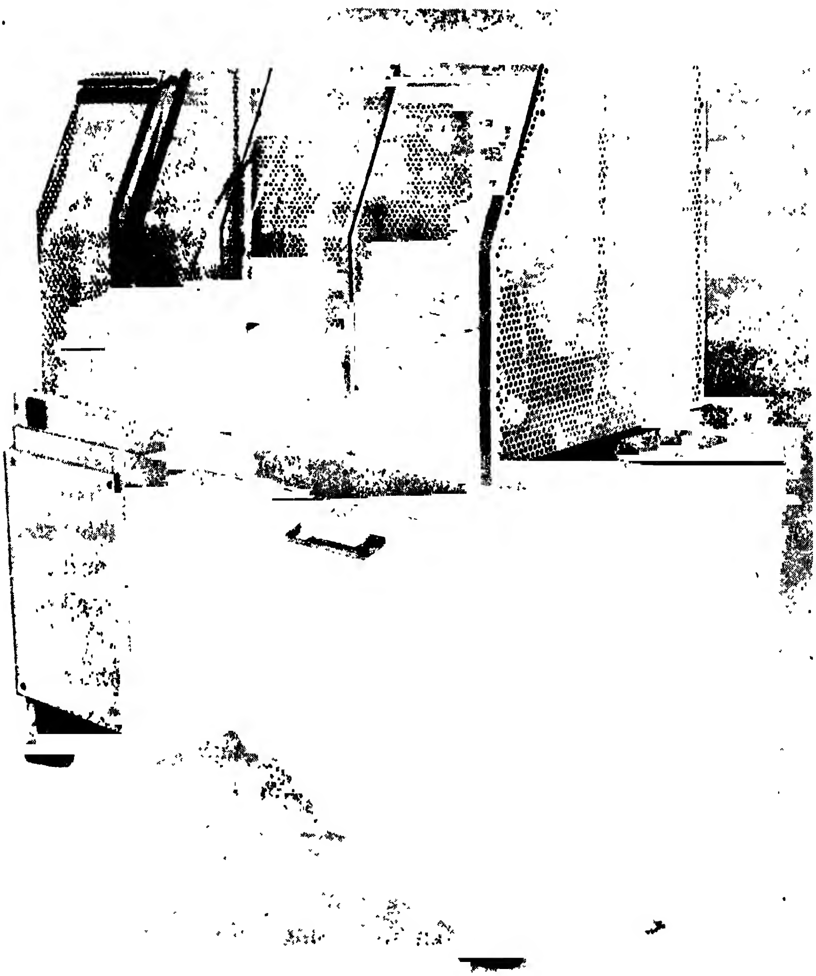
The plate (Fig. 15.3) can be heated electrically or with a hot air gun until the ends of the parts are spongy and soft, the time for which they are in contact with the plate being critical, as this determines the temperature rise of the parts. With electric heating the current is switched off automatically after a given time, both current and time being variable. With the hot air gun care must be taken not to overheat the parts. When the current is switched off the plate is immediately removed and the part ends, now in the spongy condition, are brought together and pressure applied by hand or mechanically until the parts are cool. The flash is then removed and the weld is complete. Fusion has taken place throughout the part ends and an excellent bond is obtained.

Pipes of polyethylene, coloured yellow for gas, blue for water and black for sewage, are much used today and are jointed in this way. The generator used in the field is generally 110 V and equipped with an automatic timing device. Sockets, caps, reducers, tees and simple and self-tapping saddles are available for use with gas and water pipes. Pipes of length 50, 100 or 150 m are available, longer lengths being supplied on a drum. Wall thickness should be selected according to the pressure within the pipe and can vary from 20 mm to 500 mm O/D. Absolute cleanliness is essential with excellent fit, and scraping and other cutting tools are used.

Hot plate welding by machine

Hot plate welding is now used for the production of more complicated assemblies (e.g. in the automobile and domestic industries) which are not suitable for injection, blow moulding or extrusion. Several types of jigs and fixtures are used for variety of mouldings giving watertight sealing, enabling different types of material to be welded together with accurate dimensions and small tolerances.

Fig. 15.12. Horizontal hot plate plastics welding machine. Hand loaded, fully automatic welding cycle (Bielomatik). Optional extras include: vacuum pumps, mechanical clamping. Also available are special adaptations of machine sequences.



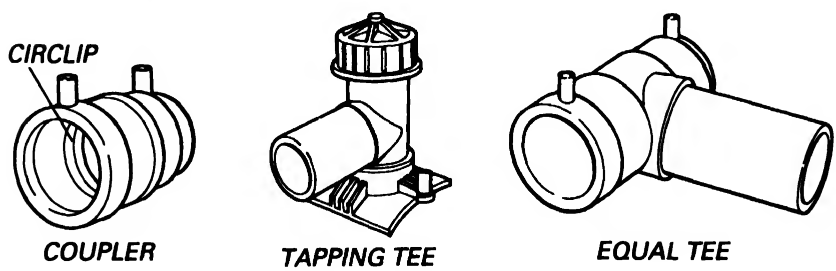
The parts to be welded are loaded onto the upper and lower plattens of the machine (Fig. 15.12). The fusion faces are then plasticized by being brought into contact with the hot plates, which are retracted automatically when the correct plasticizing point is reached. The mouldings are then brought together under pressure as with other types of hot plate welding. Upon cooling the assembly is unloaded from the machine.

Complicated assemblies can be produced more cheaply in this way, because if one part of the assembly is damaged or cracked, that part can be repaired by welding after correct preparation in the manner described in the section on hot air welding.

Electric fusion welding

This method can be performed using fittings such as couplers, reducers, branch saddles etc., which have electrical resistance coils moulded into each fitting. The ends of the heating elements in each fitting are brought to two connecting pillars. Power for the element is supplied from a generator fitted with an automatic timing control, which is essential since it identifies the fitting and gives the welding current and time for each operation. The generator is rated as 40 V and 50 A maximum. Before pipes are joined, they are prepared by machining the ends with a cutter, scraped if necessary, and scrupulously cleaned. They are then pushed into the coupling which has a central circlip to ensure that they are pushed in by an equal amount (Fig. 15.13). The terminals of the fitting are connected to the generator and the correct current and timing for the welding operation is automatically selected. This method is suitable for laying pipes in trenches. When pipes and coupling are brought to the correct temperature they are quite spongy or in a plasticized state; coupling and pipes fuse together at this stage. The electrical wires are disconnected from the pillars and the coupling is allowed to cool. The work may be done in a narrow trench when required and the coupling, or

Fig. 15.13. Types of joints and fittings required for electric fusion welding.



any type of fitting being used, is left in position in the trench, which is then filled in. The various joints made in this way can be subjected to tests for internal pressure (say 10 bar), tensile strength and impact for saddles.

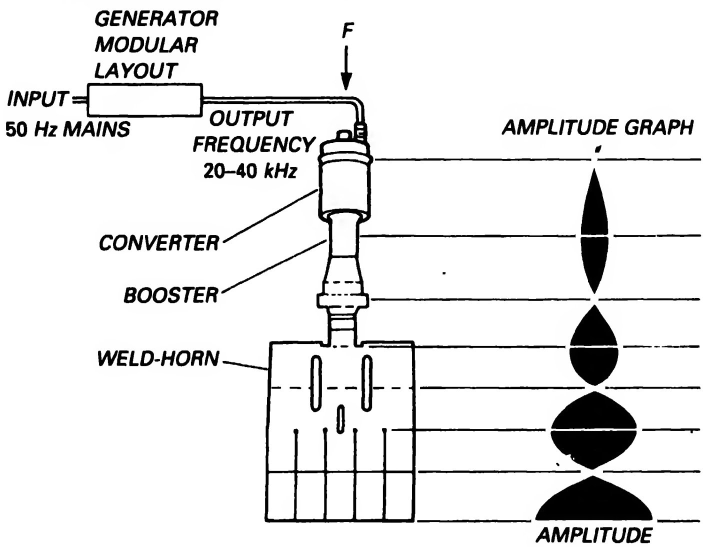
It will be noted that with hot plate and electric fusion methods of welding, no extra filling rods are required. The electric fusion jointing of pipes is more convenient than the hot plate method and is largely used today.

Ultrasonic welding

With this method of machine welding, an alternating current of frequency 50 Hz is connected to a generator where its frequency is changed to 20–40 kHz (20000–40000 Hz) the capacity of the generator being 100–3000 W as required (Fig. 15.14). This ultrasonic current, say at 20 kHz, is fed into a transducer (which is generally a piezo-electric device) which changes the ultrasonic electric vibrations into a mechanical vibration also at 20 kHz. (The magneto-strictive types are little used nowadays.)

A piezo-electric material increases in length when a current flows through a coil surrounding the device and changes the alternating electric field into mechanical movement. Examples of piezo-electric materials are quartz, tourmaline (a silicate of boron and aluminium with additions of

Fig. 15.14. Resonant unit, showing various amplitude gains in ultrasonic welding (piezo-electric crystal transducer) (Bielomatik).



magnesium iron and other alkaline metals and fluorine) and Rochelle salt (sodium potassium tartrate etc.). Present-day transducers have thin sheets or wafers of piezo-electric material bonded to a central metal laminated core while two metal strips are bonded to the other faces of the piezo-electric material, the lengths of these strips being about one half that of sound in the metal core, so that the assembly is resonant at the given frequency and vibrates ultrasonically at the frequency of the input current. The welding head to which the transducer is fixed is inserted to get the gain in amplitude which cannot be obtained from the horn alone. It consists of two parts: the booster and the horn, or tool holder. The booster increases the amplitude of the vibration and is clamped at its nodal point (the point of least vibration). If the booster has a larger diameter where it is attached to the transducer body than where it is attached to the horn, the amplitude is increased and the ratio of the masses of metal on each side of the node determines the increase or decrease of the vibration.

The horn is specially designed to have the correct sonic properties, and transmits pressure to the welded surfaces and vibrates to make the weld. It must have good mechanical strength; the end which makes the weld can be of cylindrical shape, bar shape, or more complex shapes according to the parts to be welded. The horn can be made of steel alloy, aluminium alloy or titanium, which all have good ultrasonic properties.

The sequence of operations is: (1) machine is loaded; (2) force is applied; (3) ultrasonic power flows for a given time; (4) hold time during cooling of the weld; (5) force is removed and machine deloaded.

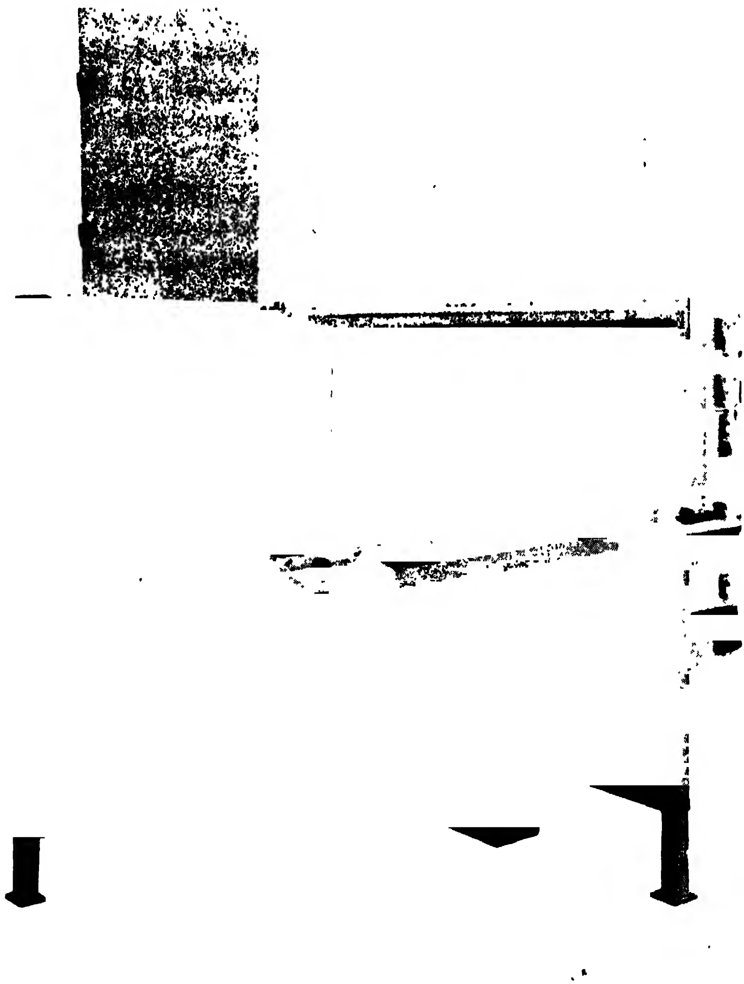
Vibration welding (linear)

This method, which is mechanized (Fig. 15.15) has an upper plate (or platten) on which one of the parts to be welded is secured; the lower platten carries the other part to be welded. The upper platten is vibrated hydraulically and is connected to springs. The frequency of vibration (180–300 Hz) is infinitely adjustable, as is the amplitude of vibration (0–1.2 mm each way, i.e. 2.4 mm in total). When the plattens are in the unloaded position there is ample space between them to mount the parts, which can be clamped hydraulically if required. When the parts are brought together, the upper platten vibrates, the frequency being varied as required. When the parts are plasticized they are brought together with up to 60 bar pressure. The above figures are for reference only. Particular examples of machines will naturally have varying degrees of vibration frequency, amplitude and pressure. Friction between the moving and

fixed parts generates the heat required for the welding process and the pressure assures good fusion. The pressure is time dependent and is reduced to a lower value for some of the welding time and the cooling time. The time cycle varies from 1 to 4 seconds in most cases.

This method is especially useful for welding thermoplastics of low

Fig. 15.15. Bielomatic linear vibration welding machine features a short amplitude and high frequency, enabling accurate welding of components even with very small clearances.



viscosity, such as various grades of nylon. It is evident that the machine is suitable for mass production of parts as there is considerable tooling required for each job. Plastics that have a low coefficient of friction, e.g. PTFE (polytetrafluorethylene), are not satisfactorily welded by this method.

Joining plastics and rubbers by means of adhesives

Plastics are being increasingly used by production engineers for stressed parts of assemblies. From the welding point of view plastics can also be joined by means of adhesives. To join surfaces together they should be completely cleaned and if possible roughened by rubbing down with fine sandpaper – metallic surfaces should be grit-blasted. The surfaces should not be touched after the final cleaning. The adhesive is then applied, enough being spread to ensure that any gaps which remain between the surfaces are filled with adhesive. The surfaces are then brought together and the adhesive soon becomes hard or 'cures': the higher the ambient temperature the quicker the cure. Also the thinner the line of bond between the surfaces, the greater will be the strength of joint and the more quickly will it cure. Slight irregularities of the surfaces increase both the grip and the locking effect.

One type of adhesive in use today is the 'instant' cyanoacrylate resin. These adhesives solidify because of the reaction between them and the thin layer of moisture always present on surfaces being bonded. The liquid adhesive is prevented from congealing when in its container, by the addition of an acidic stabilizer which keeps the molecules of the adhesive apart. On being applied to the surfaces being bonded the molecules of the stabilizer are repelled or removed and the molecules of the adhesive join together and curing commences. The 'instant' description of the resin indicates that the curing process is extremely short and can be just a second or so. Not all surfaces are suitable for successful bonding because they have insufficient attraction for the molecules of the adhesive and they must be treated with other preparations which prepare their surfaces for bonding. Surfaces of polyesters and ABS (acrylonitrile-butadiene-styrene) are examples of those with good attraction while others, such as polyethylene, have little attraction.

In the original acrylic resin adhesive, the smallest molecules are those of the methyl group of esters. The polymer chains of molecules are large in number, resulting in high tensile strength bonds. The ethyl group have larger molecules so that there are fewer on a given area than for methyl esters, with the result that there is a less rigid joint, but one suitable for

bonding rubbers and plastics. In addition, the curing time is increased but with less odour.

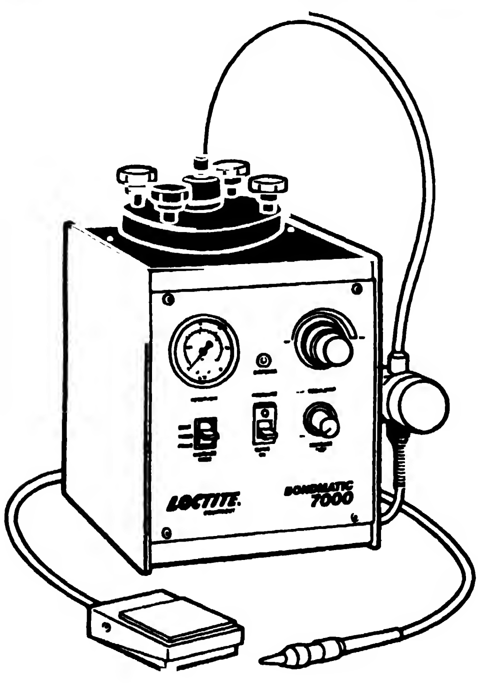
There is a wide range of adhesives covering most applications for locking threaded parts, for acidic and porous surfaces and those having great 'peel' strength with a top temperature of 100 °C and a tensile strength of 26 N/mm^2.

The 'gel' type adhesives are used for fabrics, paper, phenolics, PVC, neoprine, and nitrile rubber, with a curing time of a few seconds only. One gel has no associated fumes or odour and can be used in confined spaces, while another is clear and thick and does not run. Its top temperature is over 100 °C and it resists heat that would destroy a normal bond made with instant adhesive.

Another type is used for the assembly of pulleys, sprockets, bearings, bushes, sleeves etc., and other adhesives are used for pressed fits for cylinder liners of diesel engines. There are many other applications of this type. There is also a range of adhesives which bond the substrates of glass, ceramics, ferrites, epoxy moulding compounds, phenolic resins, laminated paper, and glass fibre laminate epoxy materials.

By the use of single-component liquids, drying rapidly at room

Fig. 15.16. Bondmatic® with foot switch and pencil.



temperature, surfaces are made suitable for bonding polyolefins and other low-energy surfaces. The liquid is applied by brush, spraying or dipping and is a polyolefin primer so that it should only be used for difficult-to-bond surfaces, e.g. polyolefins, polypropylene, PTFE and thermoplastic rubber.

With such a variety of adhesives available, each developed for a specific purpose, it is essential that the operator should contact the makers of the adhesives and obtain a full list of the adhesives available and their method of usage (Figs. 15.16 and 15.17).

Fig. 15.17. Loctite® adhesive squeeze bottle.

Some of the plastics considered with a few of their properties

Plastic	Properties
PVC (HDPVC and LDPVC)[a]	Low resistance to heat; rigid PVC higher. Low stress application, but up to 75 °C use HDPVC. Expansion 6–7 times that of steel. Low notch impact test, but this is improved by compounding with other substances. Expansion and contraction problems important when lining tanks or pipe-lines. Rigid PVC widely used for welding. Compounded with ABS, improves its impact strength, but chemical resistance suffers.
ABS (ABS/PVC and ABS/MAT: hard ABS reinforced with fibreglass, thermosetting)	Light, with high impact strength, good resistance to chemicals (alkalis and dilute acids). Used for radiator grilles, etc.

Plastic	Properties
Polypropylene (PPHD and PPLD)	Rigid and m.p. 170 °C. Low SG can be used up to 120 °C, has good mechanical strength and is resistant to most corrosive substances. Welded polypropylene can be used up to 120 °C as long as little stress is applied. Has replaced PVC and polythene in many fields. Used for sheeting, ropes and webbing. Compounded with other substances to improve qualities such as anti-cracking.
Polyethylene (Ethylene C_2H_4)	Soft and semi-flexible (makes squeeze bottles). Used for bags of all kinds. Similar in many ways to polypropylene. Used for pipes such as those used by British Gas which demand ease of connection and flexibility, for mains and smaller services. Used for injection moulded houseware (sink tidies, bowls etc.).
PTFE (Ethylene with four fluorine atoms substituted for hydrogen atoms)	Polytetrafluorethylene is mixed with other substances to give good heat resistance up to 200 °C and good dielectric properties. Welding temperatures 320–400 °C, low friction coefficient. Used for heat-resistant non-lubricated parts.
Polyacrylates (PMMA)	Polymethyl-methacrylate transmits about 92% light, has excellent optical properties and does not shatter. Chemical resistance only fair. Polyacrylates which are modified cannot be welded but can be cemented.
Polycarbonates	Low tendency to crystallize. High melting point, absorb little water, are tough and shock resistant. Yellowish or colourless. Can stand deformation but are soluble in some solvents such as methylene chloride. Resistance to chemicals rather low. Attacked by concentrated mineral acids, alkalis, ammonia, amines, ketones etc., and thus are used for dilute acids (organic and inorganic) mineral and vegetable oils and fats.
Polyamides	Contain amide group NHCO. Better known as nylon, certain types of which can be welded. Tough with high melting point. Resistant to oils, dilute acids and alkalis and some solvents. Used for textiles, hosiery, pipes, bearings and moulded parts where their higher melting point is an advantage. Some types absorb water others do not. Properties vary with the final composition.

[a] HD, high density; LD, low density.

Appendix 4

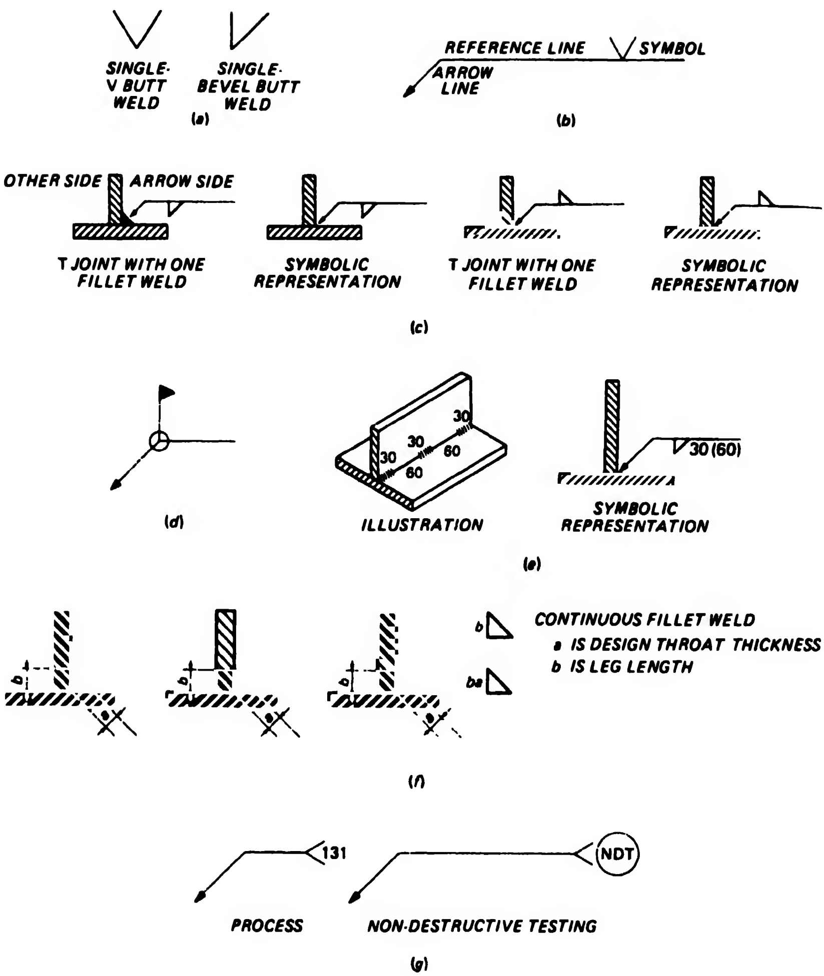
Welding symbols

A weld is indicated on a drawing by (1) a symbol (Fig. A4.1*a*) and (2) an arrow connected at an angle to a reference line usually drawn parallel to the bottom of the drawing (Fig. A4.1*b*). The side of the joint on which the arrow is placed is known as the 'arrow side' to differentiate it from the 'other side' (Fig. A4.1*c*). If the weld symbol is placed *below* the reference line, the weld face is on the *arrow-side* of the joint, while if the symbol is above the reference line the weld face is on the other side of the joint (Fig. A4.1*c*). Symbols on both sides of the reference line indicate welds to be made on both sides of the joint while if the symbol is across the reference line the weld is within the plane of the joint. A circle where arrow line meets reference line indicates that it should be a peripheral (all round) weld, while a blacked in flag at this point denotes an 'on site' weld (Fig. A4.1*d*). Intermittent runs of welding are indicated by figures denoting the welded portions, and figures in brackets the non-welded portions, after the symbol (Fig. A4.1*e*). A figure before the symbol for a fillet weld indicates the leg length. If the design throat thickness is to be included, the leg length is prefixed with the letter '*b*' and the throat thickness with the letter '*a*'. Unequal leg lengths have a × sign separating the dimensions (Fig. A4.1*f*). A fork at the end of the reference line with a number within it indicates the welding process to be employed (e.g. 131 is MIG, see Table A4.1) while a circle at this point containing the letters NDT indicates that non-destructive testing is required (Fig. A4.1*g*). Weld profiles, flat (or flush), convex and concave profiles are shown as supplementary symbols in Fig. A4.1*h*.

Figure A4.2*a* gives the elementary symbols and A4.2*b* typical uses of them. The student should study BS 499, Part 2, *Symbols for welding*, for a complete account of this subject.

Table A4.1 shows the numerical indication of processes complying with International Standard ISO 4063.

Fig. A4.1



Supplementary symbols

SHAPE	SYMBOL
FLAT (USUALLY FINISHED FLUSH)	—
CONVEX	⌒
CONCAVE	‿

Examples of supplementary symbols

DESCRIPTION	ILLUSTRATION	SYMBOL
FLAT (FLUSH) SINGLE-V BUTT WELD		
CONVEX DOUBLE V BUTT WELD		
CONCAVE FILLET WELD		
FLAT (FLUSH) SINGLE-V BUTT WELD WITH FLAT (FLUSH) BACKING RUN		

(h)

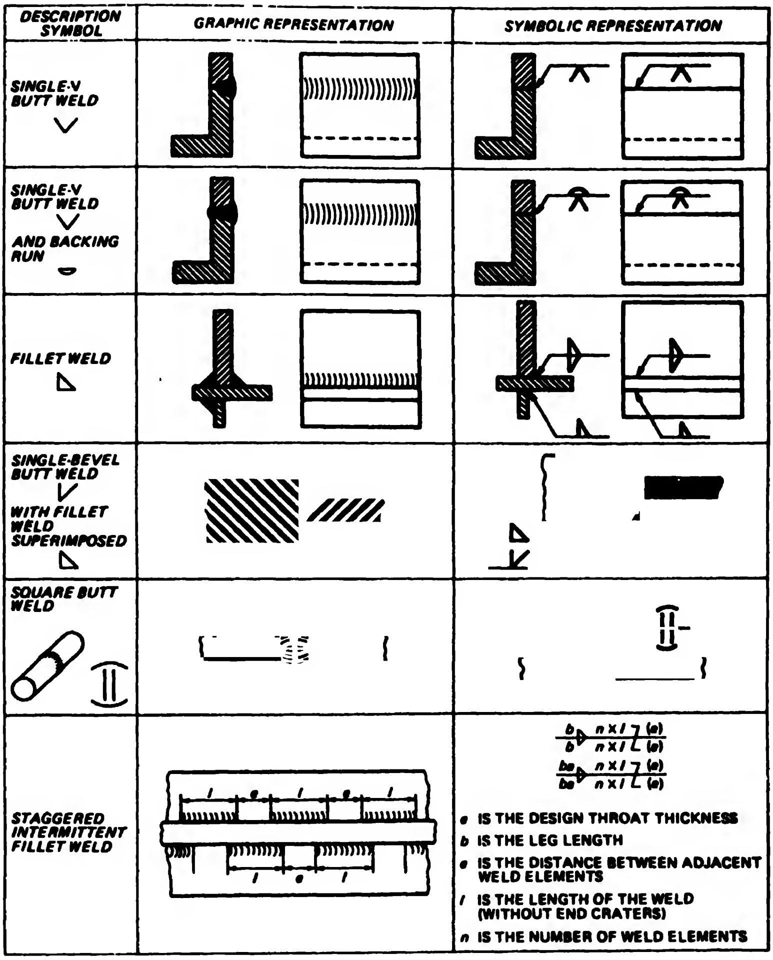
Table A4.1. *Numerical indication of process (BS 499, Part 2, 1980)**

No.	Process
1	**Arc welding**
11	Metal-arc welding without gas protection
111	Metal-arc welding with covered electrode
112	Gravity arc welding with covered electrode
113	Bare wire metal arc welding
114	Flux cored metal-arc welding
115	Coated wire metal-arc welding
118	Firecracker welding
12	Submerged arc welding
121	Submerged arc welding with wire electrode
122	Submerged arc welding with strip electrode
13	Gas shielded metal-arc welding
131	MIG welding
135	MAG welding: metal-arc welding with non-inert gas shield
136	Flux cored metal-arc welding with non-inert gas shield
14	Gas-shielded welding with non-consumable electrode
141	TIG welding
149	Atomic-hydrogen welding
15	Plasma arc welding
18	Other arc welding processes
181	Carbon arc welding
185	Rotating arc welding
2	**Resistance welding**
21	Spot welding
22	Seam welding
221	Lap seam welding
225	Seam welding with strip
23	Projection welding
24	Flash welding
25	Resistance butt welding
29	Other resistance welding processes
291	HF resistance welding
3	**Gas welding**
31	Oxy-fuel gas welding
311	Oxy-acetylene welding
312	Oxy-propane welding
313	Oxy-hydrogen welding
32	Air fuel gas welding
321	Air-acetylene welding
322	Air-propane welding
4	**Solid phase welding; Pressure welding**
41	Ultrasonic welding
42	Friction welding
43	Forge welding
44	Welding by high mechanical energy
441	Explosive welding
45	Diffusion welding
47	Gas pressure welding
48	Cold welding
7	**Other welding processes**
71	Thermit welding
72	Electroslag welding
73	Electrogas welding
74	Induction welding
75	Light radiation welding
751	Laser welding
752	Arc image welding
753	Infrared welding
76	Electron beam welding
77	Percussion welding
78	Stud welding
781	Arc stud welding
782	Resistance stud welding
9	**Brazing, soldering and braze welding**
91	Brazing
911	Infrared brazing
912	Flame brazing
913	Furnace brazing
914	Dip brazing
915	Salt bath brazing
916	Induction brazing
917	Ultrasonic brazing
918	Resistance brazing
919	Diffusion brazing
923	Friction brazing
924	Vacuum brazing
93	Other brazing processes
94	Soldering
941	Infrared soldering
942	Flame soldering
943	Furnace soldering
944	Dip soldering
945	Salt bath soldering
946	Induction soldering
947	Ultrasonic soldering
948	Resistance soldering
949	Diffusion soldering
951	Flow soldering
952	Soldering with soldering iron
953	Friction soldering
954	Vacuum soldering
96	Other soldering processes
97	Braze welding
971	Gas braze welding
972	Arc braze welding

Fig. A4.2. (*a*) Elementary welding symbols (BS 499, Part 2, 1980).

DESCRIPTION	SECTIONAL REPRESENTATION	SYMBOL
1. BUTT WELD BETWEEN FLANGED PLATES (FLANGES MELTED DOWN COMPLETELY)		
2. SQUARE BUTT WELD		
3. SINGLE-V BUTT WELD		
4. SINGLE-BEVEL BUTT WELD		
5. SINGLE-V BUTT WELD WITH BROAD ROOT FACE		
6. SINGLE-BEVEL BUTT WELD WITH BROAD ROOT FACE		
7. SINGLE-U BUTT WELD		
8. SINGLE-J BUTT WELD		
9. BACKING OR SEALING RUN		
10. FILLET WELD		
11. PLUG WELD (CIRCULAR OR ELONGATED HOLE, COMPLETELY FILLED)	ILLUSTRATION 	
12. SPOT WELD (RESISTANCE OR ARC WELDING) OR PROJECTION WELD	 (a) RESISTANCE (b) ARC	
13. SEAM WELD		

Fig. A4.2. (*b*) Examples of uses of symbols (BS 499, Part 2, 1980).



American welding symbols

From *Standard Welding Symbols and Rules for their Use*, A2.4.79 (reprint 1983), published by The American Welding Society

Note: A groove weld is a weld made in the groove between two members to be joined.

Fig. A4.3. Location of information on welding symbols.

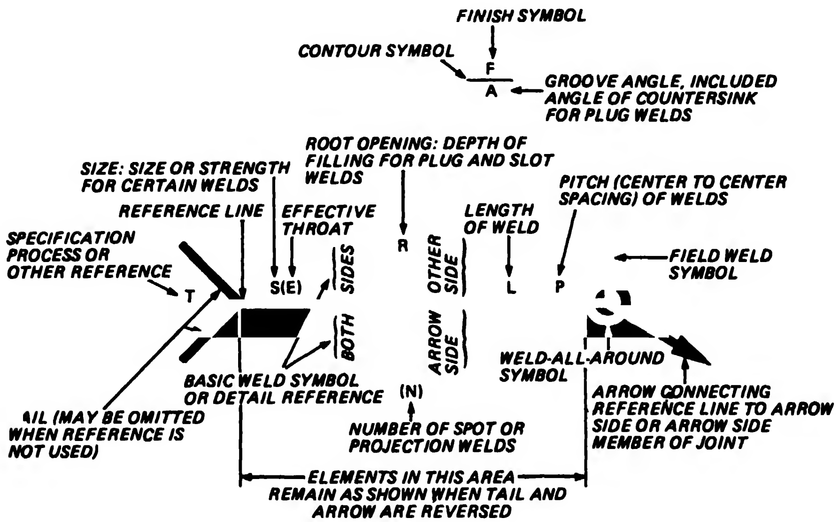


Fig. A4.4. Welding symbols.

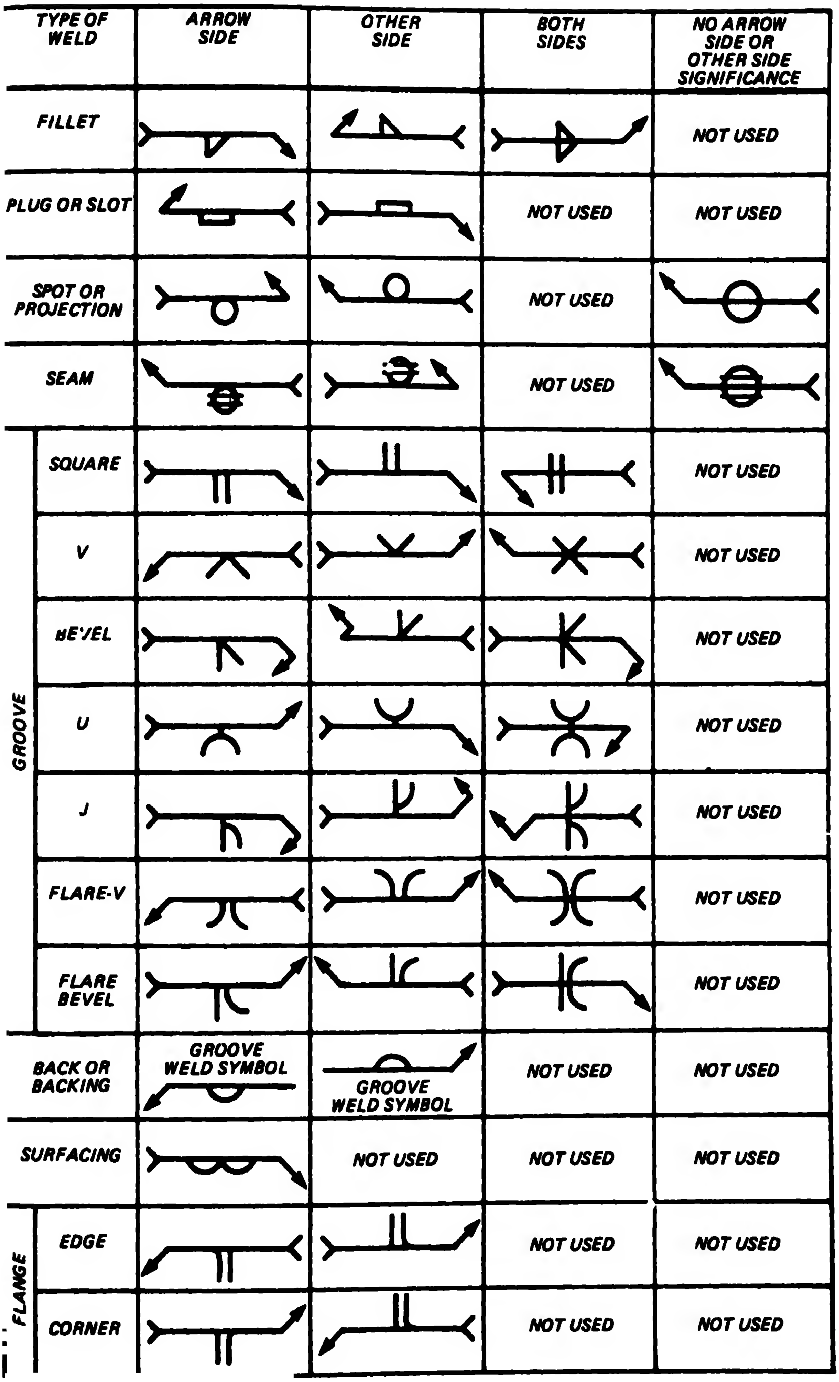


Fig. A4.5. Supplementary welding symbols.

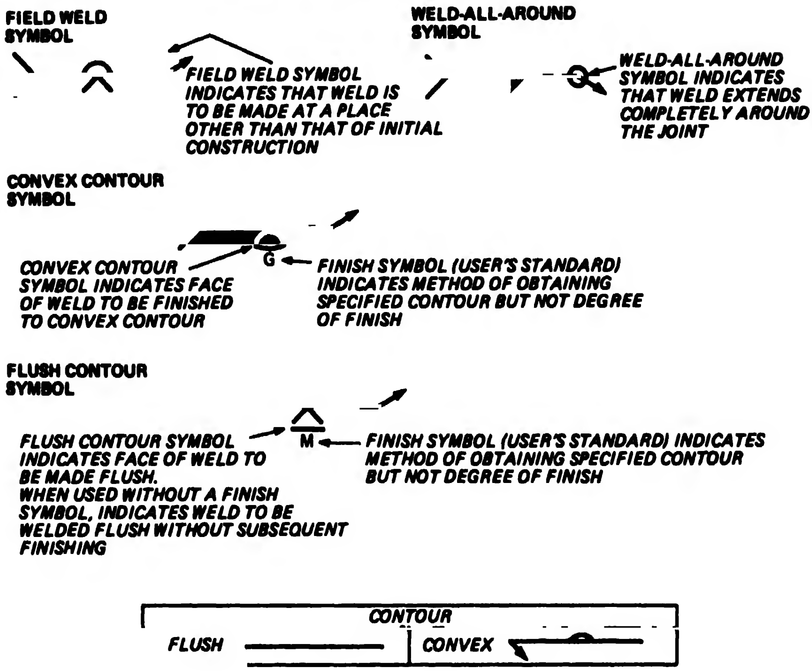
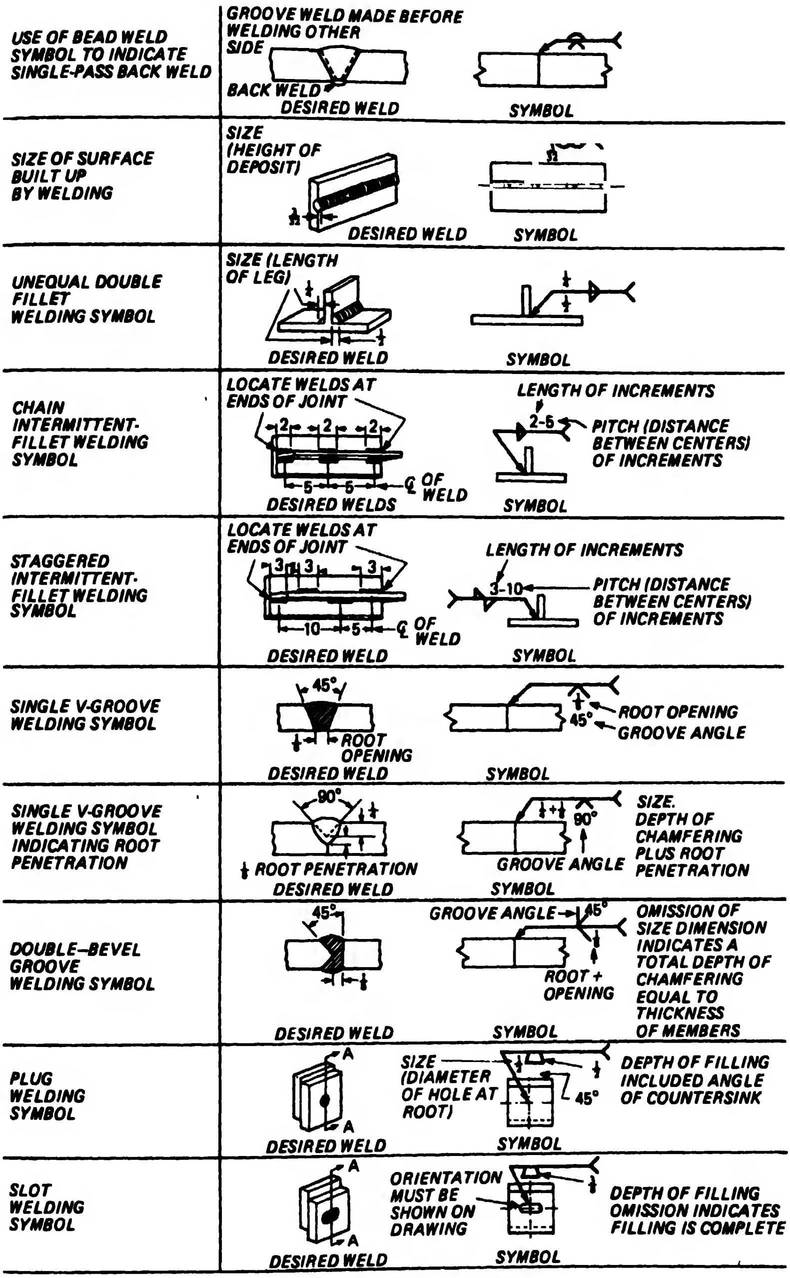


Fig. A4.6. Other typical welding symbols.



MEASUREMENTS ARE IN INCHES

Appendix 5

Simplified notes on the operation of a thyristor

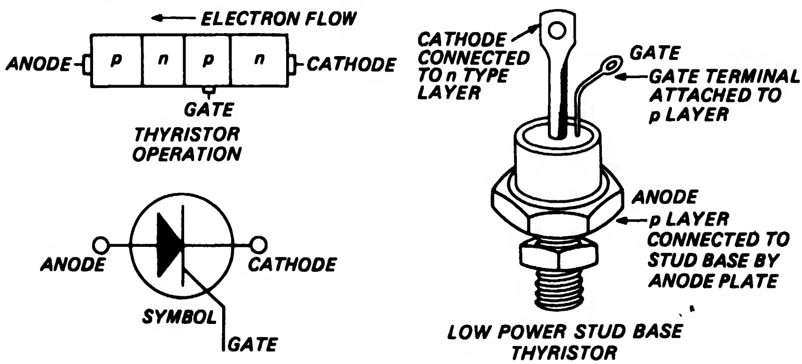
An 'n' type silicon wafer or element has impurities such as antimony, arsenic or phosphorus added to it to increase the number of negatively charged electrons available, termed 'doping'.

A 'p' type has impurities such as indium, gallium or boron added to increase the number of positive carriers or 'holes' available.

Both types have increased conductivity compared with the pure silicon.

When 'n' and 'p' types are placed in contact this forms a diode (two elements) and this will pass a current in one direction but not in the other (subject to certain temperature considerations), converting the a.c. input into half-wave pulsating d.c. The electrons flow from the 'n' type where there are free electrons to the 'p' type where there are positive 'holes'. By connecting four diodes in bridge connection full wave rectification is obtained (Figs. A5.1 and A5.2).

Fig. A5.1



• Gallium arsenide is now regarded as a suitable material for integrated circuits (IC) and other devices, not supplanting silicon, but being used for high speed and high frequency applications where silicon is not suitable.

The thyristor (sometimes called the silicon controlled rectifier or SCR) has four elements with three junctions and a further terminal called the 'gate' which is connected to the 'p' layer adjacent to cathode (Fig. A5.1). If the gate is connected directly to the cathode, the device blocks the flow of current in either direction. However, if, while the anode is positive with respect to the cathode, the gate is also made positive (typically by two or three volts), current will flow from anode to cathode. The current required in the gate is usually between 1/100 and 1/1000 of the maximum anode current. Once conduction has been so initiated, the gate has no further effect, and can be de-energized. Conduction will continue until the external circuit causes the current to fall to zero, when the device will revert to its blocking state. Like a diode, it will not permit reverse (cathode to anode) current flow under any conditions.

If half the diodes in a bridge rectifier are replaced by thyristors (Fig. A5.2), and an adjustable time delay is incorporated in the circuit generating the gate current, the d.c. output of the bridge may be varied from zero up to the equivalent of an ordinary diode bridge, by varying the time delay.

Fig. A5.3 shows typical waveforms for half output. A diode bridge connected to the supply shown in Fig. A5.3(*a*) would produce a d.c. output voltage as in (*b*). However, by using thyristors and delaying the firing pulses by a quarter of a cycle after the thyristor anodes become positive, the output voltage is halved. Fig. A5.3(*c*) shows the gate pulse timing, and (*d*) the resultant d.c. voltage.

Fig. A5.2 also shows, in simplified form, automatic control of this firing delay. The desired current is set by a single control knob on potentiometer *C*. This is compared electronically with the measured value of current from sensor *H* and the pulse timing adjusted automatically to maintain the current at the set level.

Fig. A5.2. Simplified schematic diagram for one knob control of welding current by thyristor (SCR).

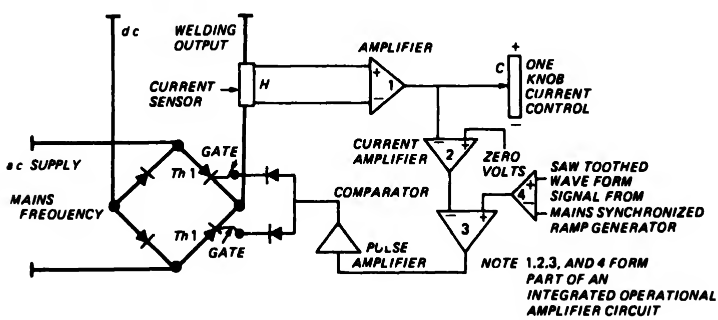
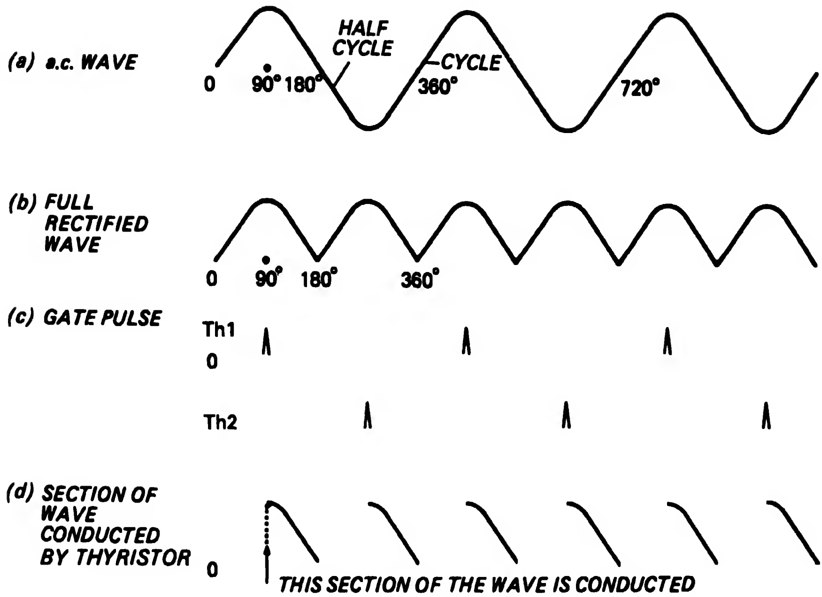
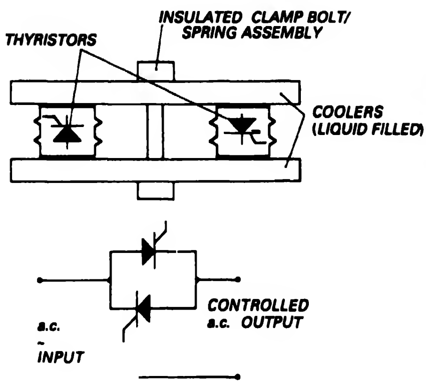


Fig. A5.3





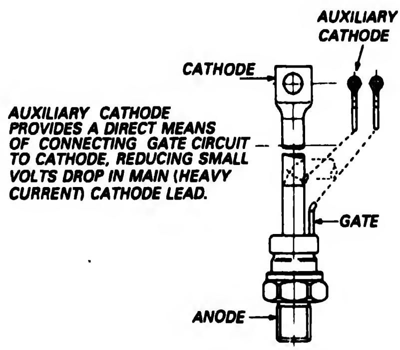


Fig. A5.4 (*b*) Thyristor: 325 A (RMS); length ~ 210 mm.

Fig. A5.4 (*a*) Typical a.c. controller (thyristors in anti-parallel).

A number of other circuits are available, including three phase and a.c. controllers, the latter producing a regulated *alternating* output (Fig. A5.4).

Appendix 6

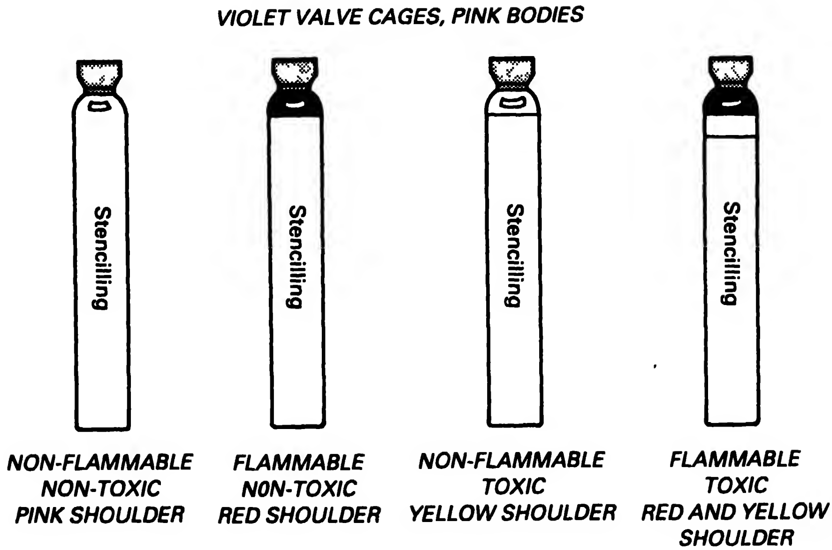
Proprietary gases and mixtures

Cylinder colour identification

Gases and gas mixtures are identified by colours as recommended in BS 349, 1973. The contents of the cylinder are indicated by the name(s) and chemical formula(e) on a label on the shoulder of the cylinder. Secondary identification is by the use of recommended base colours on the body of the cylinder and coloured bands on the cylinder to indicate the type of gas.

Gas	Cylinder colour
Acetylene	Maroon
Air (not breathing quality)	Grey
Argon	Blue
Carbon dioxide, commercial vapour withdrawal	Black
Carbon dioxide, commercial liquid withdrawal	Black with white stripes down length of cylinder
Hydrogen	Red
Nitrogen	Grey with black shoulder
Oxygen	Black
Propane	Red, wider and shorter cylinder
Argon/carbon dioxide	Blue, green band on cylinder
Argon/helium	Blue, green band on shoulder
Argon/hydrogen	Blue, red band on shoulder
Argon/oxygen	Blue, black band on shoulder
Nitrogen/hydrogen	Grey with red band or red with grey band

Fig. A6.1. Special mixtures.



AGA GAS Ltd. Selection of gases

Gas	Cylinder contents	Applications
Argon	Ar 99.99 %	TIG, MIG (GTAW, GMAW) and plasma welding, root purging. Nickel based alloys and high alloy steels (stainless steel). Copper and its alloys
Helium	He	Aluminium welding with a.c. and also straight polarity d.c. (d.c.e.n.)
AGA MIX® UN	Ar 80 %, CO_2 20 %	MAG (GMAW) welding mild and low alloy steel
AGA MIX® ST	Ar 98 %, CO_2 2 %	MIG, MAG (GMAW) welding stainless and low alloy steel. Not low carbon stainless steel
AGA MIX® SP	Ar 92 %, CO_2 8 %	MAG welding low alloy steel and mild steel, mainly spray and pulse
AGA MIX® SH	Ar 75 %, CO_2 25 %	MAG welding mild and low alloy steel, mainly short arc
AGA MIX® O_2	Ar 98 %, O_2 2 %	MAG welding stainless steel not less than 0.03 % C. Mainly for spray arc
AGA MIX® H5	Ar 95 %, H_2 5 %	Plasma cutting
AGA MIX® H20	Ar 80 %, H_2 20 %	Plasma cutting
AGA MIX® H35	Ar 65 %, H_2 35 %	Plasma cutting
AGA MIX® He30	Ar 70 %, He 30 %	Welding copper and its alloys
AGA MIX® He70	Ar 30 %, He 70 %	Welding copper and its alloys and titanium
AGA MIX® N_2	Ar 98 %, N 2 %	Welding duplex stainless steels
AGA MISON®	Ar with less than 0.03 % NO	In every case where argon is indicated
AGA MIX® NH	H_2 10 %, N_2 90 %	Used as root protection when welding stainless steel
Argon +	(pure)	Welding titanium
Nitrogen	N_2	Gas purging. Plasma cutting

Gases marked ® are trade names of AGA GAS Ltd.

Industrial gases and mixtures supplied by Air Products plc

Name	Cylinder contents	Cylinder colours	Applications
Oxygen	O_2	Black	
Nitrogen	N_2	Grey with black shoulder	
Helium	He	Brown	
Argon	Ar	Peacock blue	
Hydrogen	H_2	Red	
Coogar® 5	Ar 93%, CO_2 5%, O_2 2%		MIG/MAG welding of steel 10 mm thick and below
Coogar® 20	Ar 78%, CO_2 20%, O_2 2%	Peacock blue with pastel purple shoulder and contents stencilled in black	MIG/MAG welding of steel 10 mm thick and above
Coogar® SG	Ar 83%, CO_2 15%, O_2 2%		Synergic pulse and standard MIG/MAG welding of steels, all thicknesses and positions
Astec® 15	He 75%, Ar 23.5%, CO_2 1.5%		MIG/MAG welding of low alloy steels and austenitic stainless steels with dip transfer
Astec® S3	He 35%, Ar 63%, CO_2 2%		Synergic pulse and standard MIG/MAG for high quality welds in stainless steels
Astec® 25	He 75%, Ar 25%	Pale blue with contents stencilled in black	MIG and TIG applications on high thermal conductivity – non-ferrous metals
Astec® 30	He 30%, Ar 70%		MIG and TIG applications on high thermal conductivity – non-ferrous metals
Astec® 50	He 50%, Ar 50%		MIG/MAG and synergic pulse weld overlay/surfacing applications

Quasar®	Ar 98 %, O_2 2 %	Supplied in liquid form by Minitank	MIG/MAG welding of steels and stainless steels, recommended for use with robotics or automatic applications on thinner section metals
Hytec® 1	Ar 99 %, H_2 1 %	Pastel purple with red shoulder and contents stencilled in black	Manual TIG applications on stainless steel
Hytec® 3	Ar 97 %, H_2 3 %		Manual TIG applications on stainless steel
Hytec® 5	Ar 95 %, H_2 5 %		Automatic and orbital TIG, plasma welding
Hytec® 35	Ar 65 %, H_2 35 %		High quality plasma cutting of stainless steel, aluminium and nickel alloys
Acetylene	C_2H_2	Maroon	Oxy-acetylene cutting, brazing and welding applications
Apachi-plus®	C_3H_8	Orange with red neck	Fuel gas for cutting, brazing and thermal spraying applications
Propane	C_4H_{10}	Red with green neck	Heating and cutting

Gases marked ® are the trade names of Air Products plc.

BOC Ltd (British Oxygen Co Ltd): Shieldmaster range of gases for welding and cutting

Gas		Cylinder contents	Cylinder colours	Applications
Oxygen	h[a]	Oxygen O_2 (99.7% purity)	Black	
Nitrogen	l[b]	Nitrogen N_2 (99.99% or 99.999% purity)	Grey with black shoulder; two white circles on shoulder indicate the higher purity	
Helium	l	Helium He	Brown	
Argon	h	Pure argon Ar (99.997% purity)	Blue	
		High purity argon (99.999% purity)	Blue plus a certificate of quality	
Carbon dioxide	l	Carbon dioxide CO_2 (to BS 4105 99.8% purity)	Vapour withdrawal black; liquid withdrawal black with two vertical white stripes, full length of the cylinder	
Argoshield® 5	h	Ar 93%, CO_2 5%, O_2 2%	Blue with green band round middle of cylinder and green shoulder; individual gases denoted by shoulder label and identity disc round neck	GMA/MIG welding thin mild steel sections (dip transfer) up to 3 mm thick
Argoshield® TC	h	Ar 86%, CO_2 12%, O_2 2%		GMA/MIG welding mild steel (dip and spray transfer) 3–10 mm thick; mini MIG welding mild steel
Argoshield® 20	h	Ar 78%, CO_2 20%, O_2 2%		GMA/MIG welding mild steel (spray transfer) above 10 mm thick
Pureshield® P1		Ar 98.5%, H_2 1.5%	Blue with red band round middle of cylinder; identity disc round neck; applications and identity label above red band	GTA/TIG welding austenitic stainless steel
Pureshield® P2		Ar 65%, H_2 35%		Plasma cutting aluminium and stainless steel

Helishield® H1	l	He 83 %, Ar 15 %, CO_2 2 % and a trace of oxygen	Brown with blue band round middle of cylinder; identity disc round neck; applications and identity label above blue band	GMA/MIG welding stainless steel – dip transfer
Helishield® H2	l	He 75 %, Ar 25 %		GMA/MIG and GTA/TIG welding copper and thicker sections of aluminium
Helishield® H3	h	He 30 %, Ar 70 %		GMA/MIG and GTA/TIG welding aluminium and aluminium alloys
Helishield® H5	l	He 50 %, Ar 50 %		GMA/MIG and GTA/TIG welding nickel and nickel alloys
Helishield® H101	l	He 40 %, Ar 60 % plus some CO_2		GMA/MIG welding stainless steel, low alloy steel; spray transfer
Argomix®	h	Ar 80 %, CO_2 20 %	Blue with green band round middle of cylinder	Special applications of GMA/MIG welding mild steel; spray transfer
Argon/Hydrogen	l	Special mixtures as required	Blue with red band round middle of cylinder	Special GTA/TIG welding applications
Argonox®	h	99/1, 98/2, 95/5 % argon/oxygen	Blue with black band round middle of cylinder	GMA/MIG welding stainless and high alloy steels
Acetylene	l	Acetylene C_2H_2	Maroon	Bevelling, high speed flame cutting and welding mild steel; brazing
Propylene	h	Propylene C_3H_6	Red body, pink top and bottom	Metal spraying
Propane	h	Propane C_3H_8 to BS 4250	Red	Flame cutting mild steel; pre-heating

[a] h – heavier than air.

[b] l – lighter than air.

Gases marked ® are trade names of BOC Ltd.

Note GMA (gas metal arc) is the American term for MTG); GTA (gas tungsten arc) is the American term for TIG.

Manifolded cylinder pallet (MCP) contains 15 N size cylinders connected to a single outlet. The N cylinder is usually 200 bar pressure as is the MCP manifold.

Distillers AG Ltd: gases for welding and cutting

Gas or gas mixture	Cylinder contents			Cylinder colours	Applications
Oxygen	O_2			Black	Welding and cutting
Nitrogen	N_2			Grey, with black shoulder and guard	Freezing, purging, certain steels, plasma cutting
Helium	He			Brown cylinder, shoulder and guard	TIG welding of non-ferrous metals and alloys. General TIG applications
Argon	Ar			Peacock blue	Non-toxic, smooth arc, easy start, little spatter. Used in MIG and TIG welding and in gas mixtures
Hydrogen	H_2			Red cylinder, shoulder and guard	MAG welding of stainless steel. Very inflammable
Carbon dioxide	CO_2			Black with white stripe down cylinder length. For commercial liquid withdrawal	Sometimes used on its own for welding. Also mixed with other gases (see below)
Propane	C_3H_8			Red cylinder with valve core blue	For cutting and heating when used with oxygen
Acetylene	C_2H_2			Maroon	Welding and cutting
Air (blended)	Air			Grey cylinder and cage	Cutting
Argon and argon-based					
	Ar	CO_2	O_2		
Krysal® 5	93%	5%	2%	Peacock blue, with pink shoulder and guard	Thin low carbon steel. Low spatter, pulse arc. All positions
Krysal® 20	78%	20%	2%	Peacock blue, with pink shoulder and guard	Thick low carbon steel. Reduced spatter. Not suitable for pulse

Krysal® SM	85 %	13.5 %	1.5 %	Peacock blue, with pink shoulder and guard	Most sections low carbon steel. Smooth arc. Minimum spatter. Suitable pulse arc and has robotic uses
Krysal® G8	92 %	8 %	—	Peacock blue with pink shoulder and guard	CO_2 component controls penetration and bead shape for weld strength. Improves wetting and viscosity
Krysal® 155	80 %	15 %	5 %	Peacock blue, with pink shoulder and guard	The oxygen content stabilizes the arc, improves wetting and gives good fusion
Excellar® 8	Argon-based			Bulk liquid form	Developed for MAG welding of carbon steels and good for automatic operations
Argon–oxygen					
	Ar	O_2			
Argon/oxygen 1 %	99 %	1 %		Blue, with black shoulder; contents stencilled in black	Used for the MIG and MMA welding for stainless steel. Reasonable spatter
Argon/oxygen 2 %	98 %	2 %			
Argon/oxygen 3 %	97 %	3 %			
Helium based					
	Ar	He	CO_2		
Stellar® 30	70 %	30 %	—	Mid-brown with pink shoulder and guard	Used when argon–hydrogen is inappropriate. Deep penetration. As the helium percentage rises the arc becomes less stable. Higher helium mixtures are ideal for non-automated processes. For MIG welding of non-ferrous metals, aluminium, copper etc. TIG welding of most materials. Stellar 50 and Stellar 75 are lighter than air
Stellar® 50	50 %	50 %	—		
Stellar® 75	25 %	75 %	—		

Gas or gas mixture	Cylinder contents			Cylinder colours	Applications
Stellar® T1	minor	major	trace	Mid-brown with pink shoulder and guard	For MAG welding of stainless steels. T1 and T6 are lighter than air
Stellar® T6	major	minor	trace		
Stellar® T8	major	minor	trace		
Helihi®	Helium–air			Cylinder body brown, cage pink	Balloon gas
Argon–hydrogen					
	Ar	H_2			
Hylar® 1	99 %	1 %			
Hylar® 2	98 %	2 %			
Hylar® 3	97.5	1.5 %		Peacock blue, with signal red shoulder and pink guard	For TIG welding of stainless steels
Hylar® 5	95 %	5 %			
Hylar® 35	65 %	35 %			
Shielding gases for plasma welding					
Argon					Used both as orifice and shielding gas with some equipment.
Hylar® 5					Used as a shielding gas for plasma welding thin material.
Hylar® 35					Used for plasma cutting in certain applications

Mixtures of gases containing more than 5 % hydrogen can be explosive.
Argon is non-toxic, but both argon and carbon dioxide are asphyxiants in high concentrations. Carbon dioxide dissociates in the arc; the oxygen produced increases wetting. The occupational exposure standard (OES) has been set at 5000 vpm. Carbon dioxide in the atmosphere is approximately 350 vpm.
A toxic gas is one that in its pure form has an OES as defined by the Health and Safety Executive of less than 500 vpm.
Gases marked ® are trade names of Distillers AG Ltd.

Appendix 7

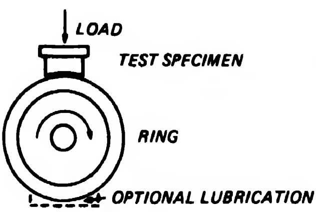
Tests for wear-resistant surfaces

The following tests for wear are used

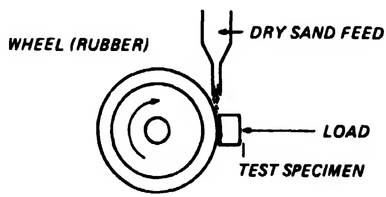
(1) *Adhesive wear test* in which a test specimen in the form of a block is pressed or loaded against a rotating alloy wear test specimen in the form of a ring or of a comparison standard. The block and ring may be of similar or dissimilar alloy and the ring may be lubricated (optional). The volume loss for various loads is measured for a given number of revolutions.

(2) *Abrasive wear test* in which dry sand is fed between the surfaces of a wear test specimen which is pressed or loaded against a rotating rubber wheel. The volume loss of the specimen for a given number of revolutions and load is measured.

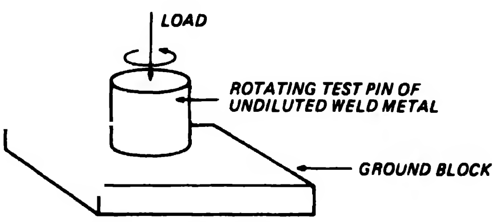
(3) *Galling test* in which a rotating cylindrical pin made from undiluted weld metal (e.g. TIG) is pressed (loaded) against a standard ground block and the stress in kg/mm² at which visual sign of material transfer (galling) occurs after one revolution of the pin is noted.



a ADHESIVE WEAR



b ABRASIVE WEAR



c GALLING (MATERIAL TRANSFER)

Appendix 8

Conversion factors

inch	mm	Preferred mm	inch	mm	Preferred mm
$\frac{1}{64}$	0.4	—	$\frac{5}{16}$	8.0	8
$\frac{1}{32}$	0.8	—	$\frac{3}{8}$	9.5	10
$\frac{1}{16}$	1.6	—	$\frac{7}{16}$	11.1	11
$\frac{3}{32}$	2.4	—	$\frac{1}{2}$	12.7	12
$\frac{1}{8}$	3.2	3	$\frac{9}{16}$	14.4	—
$\frac{5}{32}$	4.0	4	$\frac{5}{8}$	16.0	15
$\frac{3}{16}$	4.8	5	$\frac{11}{16}$	17.6	18
$\frac{1}{4}$	6.4	6	$\frac{3}{4}$	19.0	20
			$\frac{7}{8}$	22.4	22
			1	25.4	25

SWG	mm	SWG	mm
28	0.38	16	1.6
26	0.46	14	2.0
24	0.56	12	2.5
22	0.71	10	3.25
20	0.91	8	4.0
18	1.22	6	5.0
		4	5.9

1 kgf = 9.8 N (10 N approx.).
1 bar = 14.5 lbf/in^2 = 0.1 N/mm^2.
1 tonf/in^2 = 15.4 N/mm^2 = 1.54 hbar.
1000 mb = 1 bar = 14.5 lbf/in^2 = 1 kgf/cm^2.
1 hbar = 100 bar.
1 cu. ft = 0.028 m^3 = 28.3 litres.

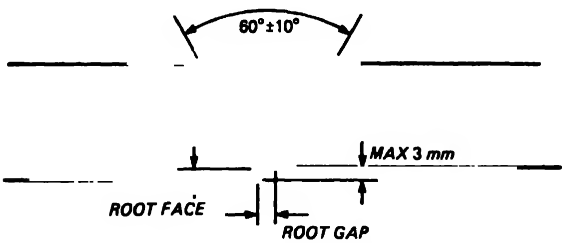
Appendix 9

Low hydrogen electrode, downhill pipe welding

A d.c. power source is used as with cellulosic rods (p. 415) and is usually engine driven in the field, the electrode being connected to the − ve pole. Weld metal deposition is faster than with cellulosic or uphill low hydrogen methods and a short arc is used with no 'pumping' of the electrode. Since shrinkage is important, if internal clamps are used there should be more spacers. The preparation of a joint using different diameter pipes is show in Fig. A9.1 and the tack welds should be tapered at each end.

For the root run the electrode should lightly touch the joint and the weld should continue through 6 o'clock about 2 mm towards 7 o'clock to facilitate link up with the run to be deposited on the other side. There is no weave and keeping a short arc and high travel rate the slag is kept above the

Fig. A9.1. Joint preparation.



ROOT FACE

ELECTRODE DIAMETER	FACE
2.5 *mm*	
3.25 *mm*	

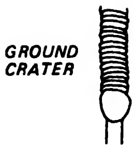
ROOT GAP

ELECTRODE DIAMETER	GAP
2.5 *mm*	2.5 *mm* + 1.0 *mm*
3.25 *mm*	2.5 *mm* + 1.0 *mm*

Note: further reduction of the root gap is possible in thinner wall thicknesses, for experienced pipeline welders using the 3.25 *mm* electrode.

Fig. A9.2

Fig. A9.3



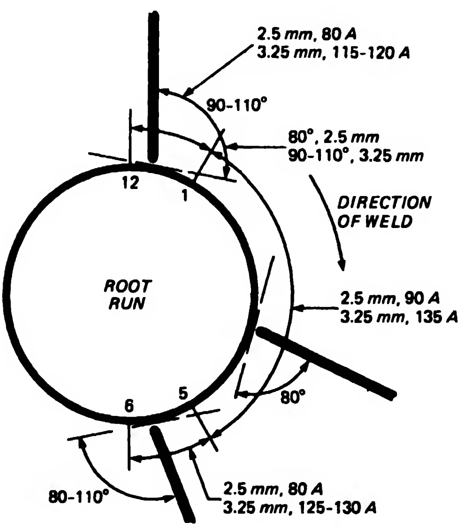
arc at a distance of about the coating diameter. The arc is broken by turning into the bevels and the metal is tailed off as shown in Fig. A9.2.

The finishing crater should be ground to a pear-shaped taper (Fig. A9.3) and the next electrode is started about 10 mm above the top end of the tapered crater. Slag is removed from each run with power brush and chipping hammer and grinding is used to remove any excess metal generally from 4 to 6 o'clock. The penetration bead may be slightly concave but has a smooth tie-in with the pipe metal and is acceptable. Too much heat gives increasingly convex penetration and is due to too slow travel or too high a current.

Avoid burn through between 12 and 1 o'clock when using a leading arc by keeping the arc as short as possible and directing it alternately to each side of the joint. Fig. A9.4 shows angles of electrode, electrode diameters and currents.

For the filling and capping runs the arc is kept short with a weave not exceeding 3 to 4 times the core wire diameter and the slag–electrode distance

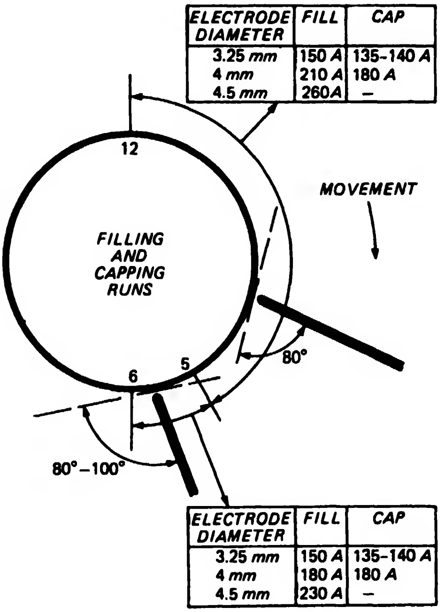
Fig. A9.4. Angles of electrode, electrode diameters and currents, root run.



should be about 10 mm (Fig. A9.6). Fig. A9.5 shows angles of electrode, electrode diameter and currents, Fig. A9.6 the slag–electrode tip distance and Fig. A9.7 the restrike and electrode movement.

Low hydrogen electrodes are supplied in sealed air-tight tins and should be stored as on p.355, the hydrogen content being 5 ml per 100 g of weld metal (IS03690). If the electrodes are left unused for 8 hours or more they should be rebaked at 280 °C + 20°C for 1 hour and stored in a holding oven at 120–150 °C until used. They should not be exposed to any damp conditions

Fig. A9.5. Angles of electrode, electrode diameters and currents, filling and capping runs.



ELECTRODE DIAMETER	FILL	CAP
3.25 mm	150 A	135–140 A
4 mm	210 A	180 A
4.5 mm	260A	–

ELECTRODE DIAMETER	FILL	CAP
3.25 mm	150 A	135–140 A
4 mm	180 A	180 A
4.5 mm	230 A	–

Fig. A9.6

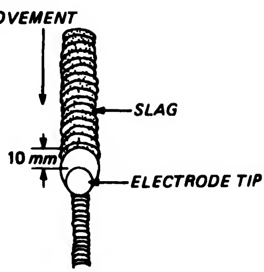
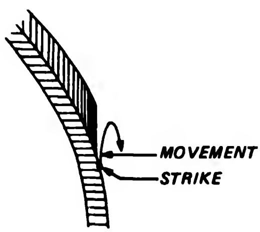


Fig. A9.7



during use and the joint should be completely free of all moisture. The weld metal has high resistance to cracking and is of composition C 0.06–0.09%, Mn 1.00–1.40%, Si 0.03–0.07% and classification AWS A5.5 E8018-G BS 639 E5154B 120 90(H).

Appendix 10

The manufacture of extruded MMA electrodes

As previously stated, almost all electrodes are produced by the extrusion process. The present day electrode consists of a core wire, centrally placed in a coating, usually silicate bonded (p. 60). Double coated electrodes are also produced.

A semi-automatic production line may consist of the following:

(1) *Wire drawing*. Non-slip hydraulic machines draw the wire through dies to the correct size, after which the wire is stored on reels.

(2) *Wire cutting*. The wire is then straightened and cut to electrode length, giving burr-free wire rods of any required length which are stacked in bins.

(3) *The coating*. The raw materials of the coatings are kept in raw material silos and from these the materials are sieved and dosed. It is the type and composition of these materials that determines the characteristic of the particular electrode. The dosing installations consist of a number of silos each fitted with a discharge system, dosing control and weighing facilities.

(4) *Silicate storing* consists of tanks that are temperature controlled and from which the silicate is pumped to the mixer.

(5) *Dry blending and wet mixing*. The batch is first thoroughly mixed in the dry state and then a measured quantity of silicate is added from a dosing unit. The wetted batch is then roughly mixed, emptied and removed to the slug press, where it is pressed into slugs ready for extrusion.

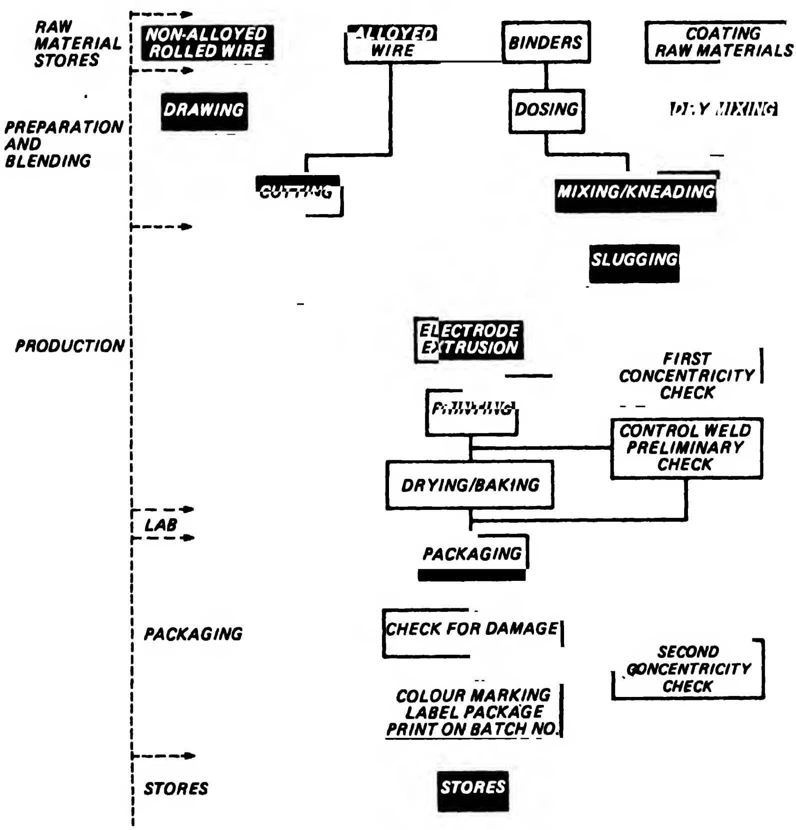
(6) *Extrusion*. The slugs are placed into the charging trough and when this is full the load of slugs is thrust into the extrusion cylinder. The breech of the hydraulic extrusion cylinder is then locked by a simple lever movement. The cut and deburred wires are stored adjacent to the wire feed from which, by opening a slide in the bin

side, the wire rods drop into the feed magazine. The extruder piston is then operated and when the flux flow pressure is reached the wire feed commences. Accelerator and drive rolls take the rods dropping from the magazine and push them axially through the press to the extrusion head where they receive their coating.

(7) *Concentricity check and brushing.* It is important that the core wire should be centrally placed in the covering (pp. 347–8). This is checked electronically and adjustments made if required. A transfer belt then takes the electrodes to a brushing station where the ends for the electrode holder and the striking tip are formed, after which the number or type of electrode is printed on the coating by a printing machine.

(8) *Drying and baking.* The electrodes are air dried to prevent cracking of the coating and are then loaded into baking ovens, after which they are ready for packing.

Fig. A10.1. Simplified diagram of electrode production process.



Where high capacity is required, two extruders are placed in parallel. When one is being charged the other is working, so that the same brushing and drying ovens are used and delay in production is minimised. In many cases the high speed wire drawing and cutting machines are fully automatic and the drying ovens are of the bucket type with conveyor chains up to 1000 m long and temperatures up to 450 °C.

Appendix 11

Notes on fire extinguishing (BS 5306, Part 3: Code of practice for selection, installation and maintenance of portable fire extinguishers)

For a fire to occur we need *oxygen*, *fuel* and *heat*.

Oxygen is present in the atmosphere and in the compressed form contained in cylinders used for oxy-acetylene or oxy-propane cutting.

Fuel may be any combustible substance such as petrol, diesel oil, paper, cleaning materials, rubber or litter etc. – anything that will burn.

Heat may be supplied by discarded cigarette ends, match sticks and, in the welding shop, by sparks from the arc or bad connections such as those at the earth or return terminal to the set. The arc is an intense source of heat and, together with the sparking, will rapidly cause ignition of any combustible solids or liquids in the immediate vicinity.

If any one of these above causes is removed, the fire will be contained. For example the oxygen supply from the atmosphere may be contained by smothering the fire with a blanket or dry sand or by turning off the oxygen supply if it is from a cylinder. The heat can be controlled by ceasing to use the arc and switching off all power supplies to prevent further arcing at poor contacts.

Classes of fire with suitable extinguishing media

(*A*) Solid materials (carbonaceous fires forming glowing embers). Use water type extinguisher (cooling method) except on electrical apparatus.

(*B*) Liquids or liquifiable solids (petrol, paraffin, wax, etc.). Use foam, dry powder, CO_2, vaporizing liquid, fire blanket, dry sand. (smothering method).

(*C*) Flammable gases, liquid petroleum gas including propane and butane, acetylene. Turn off the supply (starvation method).

(*D*) Metals (magnesium, metallic powders). Special powders containing sodium or potassium chloride are required. Such fires should be dealt with by the fire brigade.

Types of extinguishers

(1) *Carbon dioxide CO_2.* This contains liquid CO_2 under pressure, which is released as a gas when the trigger or plunger on the extinguisher is operated.
(2) *Extinguishing powder (gas cartridge).* The powder is expelled by the pressure from a gas cartridge.
(3) *Extinguishing powder (stored pressure).* The powder is expelled by pressure stored within the body of the extinguisher.
(4) *Foam (chemical).* Chemicals stored in the body of the extinguisher are allowed to mix and react, producing foam, which is expelled from the extinguisher.
(5) *Foam (gas cartridge).* Foam is expelled from the extinguisher by the pressure from a gas cartridge.
(6) *Foam (mechanical stored pressure).* Pressure stored in the body of the extinguisher expels the foam.
(7) *Halon (stored pressure).* The body of the extinguisher contains a halon which is expelled by pressure stored within the body.
(8) *Water (gas cartridge).* Water is expelled from the extinguisher by the pressure from a gas cartridge.
(9) *Water (stored pressure).* Water is expelled by pressure stored within the extinguisher body.
(10) *Water (soda-acid).* An acid–alkaline reaction within the body produces the pressure to expel the water.

Extinguishers containing dry powder, CO_2 and vaporizing liquids

These extinguishers are suitable for fires involving flammable liquids and live electrical apparatus (as are met with under welding conditions). For fires in liquids (containers or spillage) the jet or horn should be directed at the near side of the fire, which should be driven away from the operator to the far side with a side-to-side motion of the jet. If falling liquid is alight begin at the bottom and move upwards. On electrical apparatus direct the jet directly at the fire after first switching off the mains supply. If the latter is not possible, contain the fire and summon the fire brigade.

If there is no shut-off valve on the extinguisher continue discharging it over the fire area until empty. If the discharge is controlled, shut off the

extinguisher discharge when the fire is extinguished and hold it ready for any further outbreak which may occur when the atmosphere has cleared.

Do not use vaporizing liquid extinguishers in confined spaces where there is poor ventilation and a danger of fumes being inhaled.

Foam extinguishers give semi-permanent protection against contained fires and will partially extinguish a fire, which will not gain its full intensity until the foam covering is destroyed. They may be used on liquids, in tanks to protect them from ignition or from giving off flammable vapours. Dry powder and foam should not be used together unless a specially compatible powder/foam are used.

BCF extinguishers

When this type is used the bromochlorodifluoromethane, which is a stable compound, appears as a heavy mist that blankets the fire and excludes the atmospheric oxygen. It is more efficient than chlorobromomethane (CB), methyl bromide (MB) or carbon tetrachloride (CTC). It does not damage normal materials and leaves no deposit. It decomposes slightly in the heat of a flame but the amount of harmful gas produced (which has a pungent smell) has no effect on adjacent personnel even when excess BCF is used. It has high insulating properties and can be used on electrical equipment and is particularly suitable for the welding or fabrication shop since it can be used on Class *A* fires in addition to those of Class *B* and *C*.

Fire prevention where welding processes are involved

General precautions

(1) All areas must be free of litter and combustible waste with all combustible material stored in metal bins, with lids, well away from the welding processes.
(2) Make certain that all electrical cables are not chafing and connections are secure and will not cause arcing. This applies particularly to the earth or return connection to the welding set.
(3) All chemicals including cleaning fluids should be kept away from the welding area, in a store room.
(4) Oxygen cylinders should be kept in a room apart from fuel gases such as acetylene and propane (LPG), which should be kept in another room. All cylinders and manifolds should be turned off except when in use. Keep cylinder keys with the appropriate cylinders in case of urgent need.
(5) No smoking signs should be prominently displayed and should be strictly adhered to.

(6) Defects in plant and equipment should be reported at once and indicated. Faulty electrical equipment is always a fire hazard.
(7) Always read the instructions for operation of the extinguisher situated in your shop.

Notes on procedures to be followed when using welding apparatus

Leakage of oxygen, as for example from a cylinder used in the cutting process, may lead to the ignition of any glowing or red-hot material due to the rapid oxidizing action of the escaping oxygen. The gas must be turned off at the cylinder valve (leave the cylinder key attached to the cylinder so that it is never misplaced). Remember that should flames play on a cylinder containing oxygen, there is a danger of explosion due to the high pressure involved – although oxygen is non-combustible it is a powerful supporter of combustion and may cause re-ignition.

Fuel gas cylinders

LPG, acetylene, etc. and accompanying apparatus and appliances

(1) Gas leak on fire. If the fire is away from regulators and cylinders first turn off the gas supply at the cylinder or appliance valve. If this is not possible and the fire is spreading to nearby combustible material, extinguish the flames and then seal the leak, taking care that re-ignition is not possible.

If the gas is on fire near a regulator or cylinder valve first extinguish the flames if this is possible within two or three minutes of the beginning of the combustion and use a cloth or gloves (e.g. welders) to turn off the valve and guard against re-ignition.

If the valve cannot be shut, evacuate the area and call the fire brigade.

If the gas is on fire and the flames are impinging on the gas cylinders, first extinguish the flames if this is possible within two to three minutes of the conflagration. If this is not possible, divert the flames from the affected cylinder away from the other cylinders and combustible material, evacuate the area and call the fire brigade.

Any cylinders exposed to the heat of fire should be removed within 2–3 minutes. If this is not possible, evacuate the area and call the fire brigade.

A burning gas leak can be extinguished by a dry powder, BCF or water type fire extinguisher in this order of preference but small fires may be smothered with a wet blanket or cloth.

A water type fire extinguisher should be used on any adjacent burning material and whilst dry powder or BCF types can be used in this case they will have only a limited effect.

Do not continue to fight a fire if there is a danger of gas cylinders exploding or if the fire continues to grow in spite of your efforts to contain it. Remember that extinguishers are only intended to deal with small fires so that the quicker the extinguisher is brought into use the better as fires spread quickly. Position yourself between the fire and the exit from the shop so that your escape will not be cut off.

If there is any possibility of the conflagration getting out of control in the slightest degree, call the Fire Brigade whose personnel are trained in fire fighting. They must be met on arrival and the officer in charge advised of the presence and position of all gas cylinders.

(2) Gas leak. No fire.

(*a*) The danger is from an explosion if the fuel gas is ignited. Keep all sources of ignition away from the gas. Do not smoke, switch on electric lights, electrical apparatus or telephones, etc. and do not drive vehicles in the vicinity.

(*b*) Shut off the cylinder valve or pipeline. If this is impossible move the cylinder(s) to the open air so as to dissipate the gas.

(*c*) Do not re-occupy the shops until they are properly ventilated and pay attention to pockets of gas that may exist in ducting, sumps and pits and see that they are completely purged.

Appendix 12

Table of brazing alloys and fluxes

General purpose silver brazing alloys: cadmium bearing

Description	Nominal composition	Melting range (°C)		BS 1845	Remarks
		Solidus	Liquidus		
Easy-flo	50% Ag:Cu:Cd:Zn	620	630	AG1	Cadmium-bearing alloys generally offer the best combination of melting range, flow characteristics and mechanical properties. Thus, where the presence of cadmium is acceptable, they would normally be recommended as the most economical alloys.
Easy-flo No. 2	42% Ag:Cu:Cd:Zn	608	617	AG2	
DIN Argo-flo	40% Ag:Cu:Cd:Zn	595	630	—	
Argo-flo	38% Ag:Cu:Cd:Zn	608	655	—	
Mattibraze 34	34% Ag:Cu:Cd:Zn	612	668	AG11	
Argo-swift	30% Ag:Cu:Cd:Zn	607	685	AG12	
Metalflo	25% Ag:Cu:Cd:Zn:Si	606	720	—	Easy-flo, Easy-flo No. 2 and DIN Argo-flo are the lowest melting point alloys available. All three alloys have excellent flow characteristics. The highest joint strengths are obtained with Easy-flo.
Argo-bond	23% Ag:Cu:Cd:Zn	616	735	—	
Metalsil	20% Ag:Cu:Cd:Zn:Si	603	766	—	
Metalbond	17% Ag:Cu:Cd:Zn:Si	610	782	—	
Metaloy	13% Ag:Cu:Cd:Zn:Si	605	795	—	Alloys with 30–40% silver are normally considered as general-purpose alloys. They still offer good flow characteristics and melting ranges and are suitable for mechanized brazing operations.
					The low silver alloys have good fillet-forming characteristics and are widely used in fabricating brass fittings and furniture. Owing to their wide melting ranges they are not generally used as preforms due to the danger of liquation.

General purpose silver brazing alloys: cadmium free

Description	Nominal composition	Melting range (°C) Solidus	Liquidus	BS 1845	Remarks
Silver-flo 55	55% Ag:Cu:Zn:Sn	630	660	AG14	The range of cadmium-free alloys has been developed for applications where the presence of cadmium is not allowed due to the brazing environment or the service conditions of the assembly, i.e. food-handling equipment.
Silver-flo 55	45%Ag:Cu:Zn:Sn	640	680	—	
Silver-flo 452	45%Ag:Cu:Zn:Sn	640	680	—	
Silver-flo 45	45% Ag:Cu:Zn	680	700	—	
Silver-flo 44	44%Ag:Cu:Zn	675	735	—	
Silver-flo 40	40%Ag:Cu:Zn:Sn	650	710	AG20	Silver-flo 55 is the lowest melting-point alloy in the group and has been widely adopted as a substitute for Easy-flo No. 2.
Silver-flo 38	38% Ag:Cu:Zn:Sn	660	720	—	
Silver-flo 34	34%Ag:Cu:Zn:Sn	630	740	—	
Silver-flo 33	33%Ag:Cu:Zn	700	740	—	
Silver-flo 302	30%Ag:Cu:Zn:Sn	665	755	AG21	Silver-flos 30 to 45 are general-purpose alloys suitable for use on most common engineering materials.
Silver-flo 30	30%Ag:Cu:Zn	695	770	—	
Silver-flo 25	25%Ag:Cu:Zn	700	800	—	
Silver-flo 24	24% Ag:Cu:Zn	740	780	—	The alloys with less than 24% silver are widely used on copper and steel. They give a good colour match on brass, but require close temperature control due to their high melting temperature.
Silver-flo 20	20% Ag:Cu:Zn:Si	776	815	—	
Silver-flo 18	18%Ag:Cu:Zn:Si	784	816	—	
Silver-flo 16	16%Ag:Cu:Zn	790	830	—	
Silver-flo 12	12%Ag:Cu:Zn	820	840	—	Unlike the cadmium-bearing range, this group contains low silver content alloys such as Silver-flo 33, 24 and 16, with relatively high melting points, which make them ideal for step brazing.
Silver-flo 4	4% Ag:Cu:Zn	870	890	—	
Silver-flo 1	1% Ag:Cu:Zn:Si	880	890	—	

General purpose silver brazing alloys: phosphorus bearing

Description	Nominal composition	Melting range (°C)		BS 1845	Remarks
		Solidus	Liquidus		
Sil-fos	15% Ag:Cu:P	644	700**	CP1	These alloys are recommended for fluxless brazing of copper. They may also be used on brass and bronze with the application of Easy-flo Flux or Tenacity 4A Flux. They should not be used on ferrous- or nickel-base materials or nickel-bearing copper alloys. The silver bearing alloys are more ductile than the Copper-flos and are recommended where joints will be subjected to significant stress levels.
Sil-fos 5	5% Ag:Cu:P	650	710**	CP4	
Silbralloy	2% Ag:Cu:P	644	740**	CP2	
Copper-flo	7% P:Cu	714	800	CP3	
Copper-flo No. 2	6% P:Sb:Cu	690	800	CP5	
Copper-flo No. 3	6% P:Cu	714	850	CP6	

** A small percentage of higher melting point material remains at this temperature.

Silver brazing alloys for tungsten carbide

Description	Nominal composition	Melting range (°C) Solidus	Liquidus	BS 1845	Remarks
Easy-flo No. 3	50% Ag:Cu:Zn:Cd:Ni	634	656	AG9	General-purpose cadmium-containing alloy with excellent mechanical properties.
Argo-braze 38	38% Ag:Cu:Zn:Cd:Ni	615	655	—	An economical alternative to Easy-Flo No. 3 which has proved adequate for many applications.
Argo-braze 49H	49% Ag:Cu:Zn:Ni Mn	680	705	—	A cadmium-free alternative to Easy-flo No. 3. The addition of manganese enhances wetting on difficult carbides.
Argo-braze 49LM	49% Ag:Cu:Zn:Ni:Mn	670	710	—	A free-flowing alloy giving good wetting. Suitable for small carbides.
Argo-braze 40	40% Ag:Cu:Zn:Ni	670	780	—	Economical alloys with good wetting characteristics. Their application is restricted by their relatively high melting points.
Argo-braze 25	25% Ag:Cu:Zn:Ni:Mn	710	810	—	
Easy-flo Tri-foil 'C'	Easy-flo bonded to both sides of a copper shim	620	630	—	For brazing large pieces of cemented carbide. The copper ensures that a thick stress-absorbing joint is achieved.
Easy-flo Tri-foil 'CN'	Easy-flo bonded to both sides of a copper-nickel shim	620	630	—	Recommended for joints subjected to high compressive stresses during service.
AB49 Tri-foil	Argo-braze 49LM bonded to both sides of a copper shim	670	710	—	A cadmium-free alternative to Easy-flo Tri-foil 'C'

Brazing fluxes

Fluxes are normally selected on the basis of two main criteria: 1. The melting range of the brazing alloy – both solidus and liquidus should fall well within the quoted working range of the flux. 2. The parent metals to be joined – some alloys, such as aluminium bronze, require special fluxes. Copper, brass and mild steel are effectively cleaned by all fluxes.

Description	Working range °C	DIN 8511	Availability	Remarks	Residue removal
Easy-flo Flux	550–800	F-SH1	Powder/Paste	A general-purpose flux with good fluxing activity and long life at temperature. The powder has good hot-rodding characteristics.	
Easy-flo Flux Dipping Grade	550–775	F-SH1	Paste	A highly active and fluid flux which exhibits a minimum of bubbling, making it ideal for induction brazing. This paste is formulated to give a thin, stable consistency suitable for dipping.	Residues are generally soluble in hot water. Where difficulty is encountered, immersion in 10% caustic soda is suggested.
Easy-flo Flux Stainless Steel Grade	550–775	F-SH1	Powder	More active than Easy-flo Flux. Recommended for use on stainless steel with the lower melting-point brazing alloys.	
Easy-flo Flux Aluminium Bronze Grade	550–800	F-SH1	Paste	Similar for Easy-flo Flux Paste but modified for use on alloys containing up to 10% aluminium.	When finished components are heavily oxidized, cleaning and flux removal may be accomplished by the use of 10% sulphuric acid.

Tenacity Flux No. 6	550–800	F-SH1	Powder/Paste	An opaque flux due to the addition of elemental boron. Recommended for tungsten carbide, refractory metals and stainless steel.*	
Tenacity Flux No. 14	550–750	F-SH1	Powder	An extremely fluid flux principally developed to prevent red staining on brass.	
Tenacity Flux No. 4A	600–850	F-SH1/2	Powder	A general-purpose flux with good resistance to overheating, used with higher melting temperature.	
Tenacity Flux No. 5	600–900	F-SH1/2	Powder	Recommended for stainless steel and heavy assemblies, where flux exhaustion is likely to occur due to prolonged heating	Residues are virtually insoluble in water.
Tenacity Flux No. 125	750–1200	F-SH2/3	Powder/Paste	A general-purpose high temperature flux for use with the bronze alloys.	Immersion in 10% caustic soda or mechanical removal is recommended.
Tenacity Flux No. 12	800–1300	F-SH3	Powder	A fluoride-free, high temperature flux for use with 'B' Bronze and 'G' Bronze.	
Silver-flo	550–775	F-SH1	Paste	A general purpose flux paste which combines exceptional activity with low fluxing temperature and melt viscosity.	
Mattiflux 100	550–800	F-SH1	Paste	Combines a relatively low melt viscosity with a good resistance to overheating and is particularly well suited to brazing mild steel assemblies.	

* This flux is unsuitable for use on stainless steel where crevice corrosion is likely to be a hazard in service.

Specialised silver brazing alloys

		Melting range (°C)			
Description	Nominal composition	Solidus	Liquidus	BS 1845	Remarks
Silver-flo 60	60% Ag:Cu:Zn	695	730	AG13	Principally used for brazing assemblies which will be exposed to sea water. Easy-flo No. 3 and Silver-flo 55 are also suitable for marine service.
Silver-flo 43	43% Ag:Cu:Zn	690	775	AG5	
Argo-braze 56	56% Ag:Cu:In:Ni	600	711	—	Specifically developed to prevent crevice corrosion, which may result in rapid failure of joints in stainless steel when exposed to water.
Argo-braze 35	35% Ag:Cu:Sn:Ni	685	887	—	An economical alloy suitable for fluxless brazing. Principally used on stainless steel and nickel silver.
Silver-copper eutectic	72% Ag:Cu	778	778	AG7 and AG7V	Ideal for fluxless brazing of copper, nickel and metallized ceramics. Available in two grades: Grade 1 (AG7V), a high purity material for brazing assemblies which will operate in vacuum. Grade 3 (AG7) for general engineering.
RTSN	60% Ag:Cu:Sn	602	718	—	Suitable for fluxless furnace brazing. Relatively fast heating rates necessary to avoid liquation.
15% Manganese-silver	85% Ag:Mn	951	960	AG19	A copper-free alloy for brazing assemblies which will be in contact with ammonia.

Flux coated rods

Alloy	Nominal composition	Melting range (°C)	BS 1845	Remarks
Cadmium bearing				
Easy-flo No. 2	42% Ag:Cu:Zn:Cd	608–617	AG2	A very fluid alloy, ideal for small components.
DIN Argo-flo	40% Ag:Cu:Zn:Cd	595–630	—	A general-purpose alloy with good flow characteristics.
Mattibraze 34	34% Ag:Cu:Zn:Cd	612–668	AG11	Fillet-forming alloys with limited flow characteristics.
Argo-swift	30% Ag:Cu:Zn:Cd	607–685	AG12	
Cadmium free				
Silver-flo 55	55% Ag:Cu:Zn:Sn	630–660	AG14	A free-flowing alloy generally suitable for all applications where a neat appearance is required.
Silver-flo 40	40% Ag:Cu:Zn:Sn	650–710	AG20	
Silver-flo 33	33% Ag:Cu:Zn	700–740	—	A range of cadmium-free alloys with fillet-forming properties.
Silver-flo 30	30% Ag:Cu:Zn	695–770	—	
Silver-flo 20	20% Ag:Cu:Zn:Si	776–815	—	An economical alloy suitable for brazing mild steel and copper.

Copper base brazing alloys

Description	Nominal composition	Melting range (°C) Solidus	Liquidus	BS 1845	Remarks
'B' Bronze	97% Cu:Ni:B	1081	1101	CU7	Ideal substitute for pure copper in furnace brazing where joint gaps range from interference to 0.5 mm.
'C' Bronze	86% Cu:Mn:Ni	965	995	—	Suitable for furnace brazing. Requires a dewpoint of better than – 40°C, or a small addition of flux.
'D' Bronze	86% Cu:Mn:Co	980	1030	—	Recommended for brazing cemented carbide into rock drills and similar percussively loaded joints.
'F' Bronze	58% Cu:Zn:Mn:Co	890	930	—	
'G' Bronze	97% Cu:Ni:Si	1090	1100	—	The group offers a range of brazing characteristics to match different material and heat-treatment requirements.
Argentel	49% Cu:Zn:Ni:Si	913	930	CZ8	Low cost alloys ideal for use on tubular steel furniture and display racks. The high strength of Argentel makes it particularly suitable for butt joints while Argentel B offers improved flow characteristics and a lower working temperature.
Argentel B	57% Cu: Zn: Ni: Mn: Si	890	910	—	

Silver-bearing soft solders

Description	Nominal composition	Melting range (°C)		Remarks
		Solidus	Liquidus	
Plumbsol	2.5% Ag:Sn	221	225	Lead-free alloys ideal for use in plumbing and the fabrication of assemblies where toxicity is a problem.
P35	3.5% Ag:Sn	221	221	Good colour match on stainless steel.
P5	5% Ag:Sn	221	235	P35 and P5 are stronger than tin-lead alloys at elevated temperatures.
Ceramic No. 1	9% Ag:Sn:Pb	183	250	For soldering of silver-metallized components in the electronics industry.
Comsol	1.5% Ag:Sn:Pb	296	296	Good creep resistance at elevated temperatures. Suitable for soldering armature windings and radiators.
A25	2.5% Ag:Pb	304	304	For use in 'hard chlorinated waters where tin-bearing alloys
A5	5% Ag:Pb	304	370	suffer corrosion.
LM10A	10% Ag:Sn:Cu	214	275	A free-flowing alloy with above average tensile strength and creep resistance.
LM15	5% Ag:Cd:Zn	280	320	The strongest alloy in the soft solder range. Used where temperature limitations do not permit silver brazing.
LM5	5% Ag:Cd	338	390	Can be considered for applications where good strength at moderate temperatures is necessary.

Soft solder fluxes

Description	Flux residue removal	Working range (°C)	Remarks
Soft Solder Flux No. 1	Corrosive – can be removed with cold water	150–400	A general-purpose acid flux suitable for copper, brass, mild steel and stainless steel.
Soft Solder Flux No. 2	Non-corrosive – can be removed with cold water	150–400	Recommended where flux residues cannot be removed. Suitable for copper, brass and most plated surfaces.

Appendix 13

Latest plant and equipment

Fig. A13.1. For MIG process. See p. 442 for description of unit.

Fig. A13.2. For MIG, MAG (GMAW), MMA (SMAW), d.c. TIG (GTAW) and pulsed MIG. See p. 445 for description of unit.

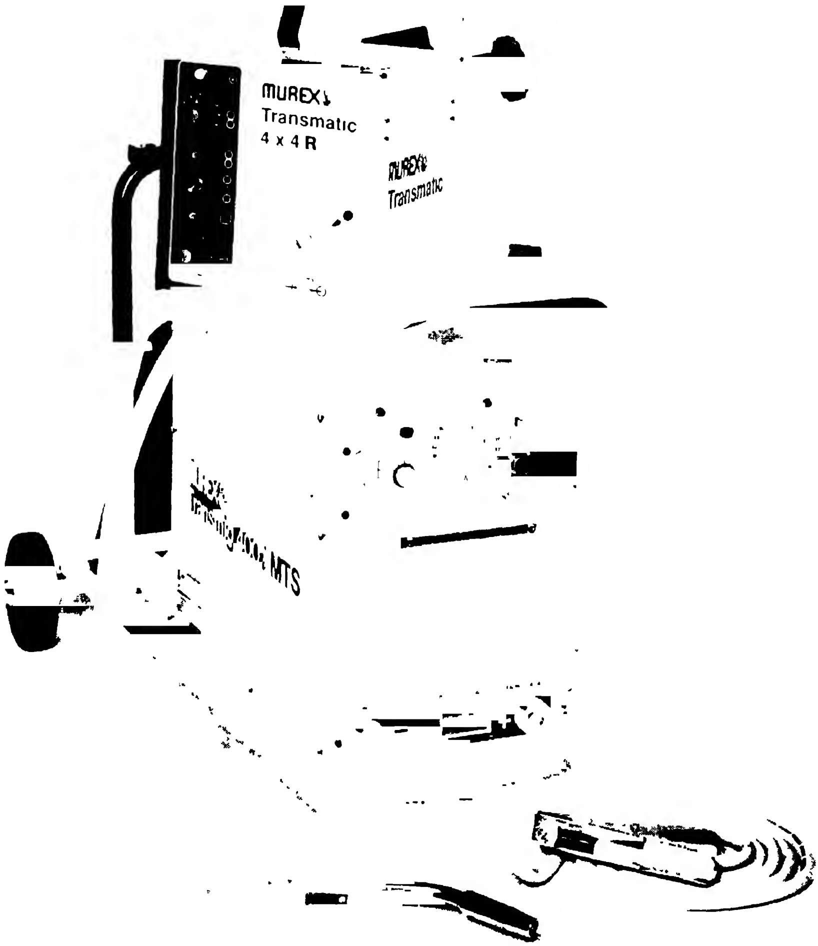


Fig. A13.3. Tectron or Maxtron unit with wire feed (termed Tectron in Europe and Maxtron in the USA). See p. 446 for description of unit.

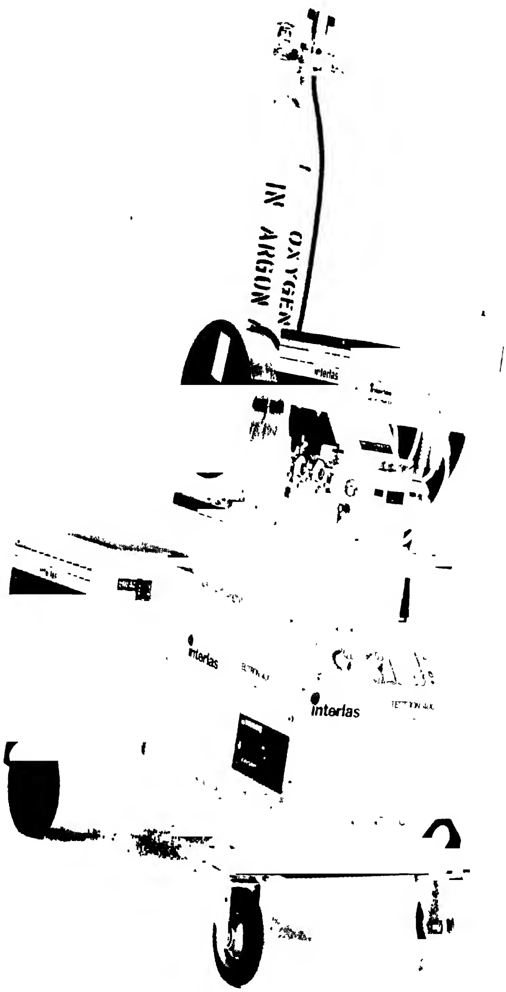


Fig. A13.4. For MMA (SMAW) and MIG (GMAW), dip spray or pulsed modes. See p. 485 for description of unit.

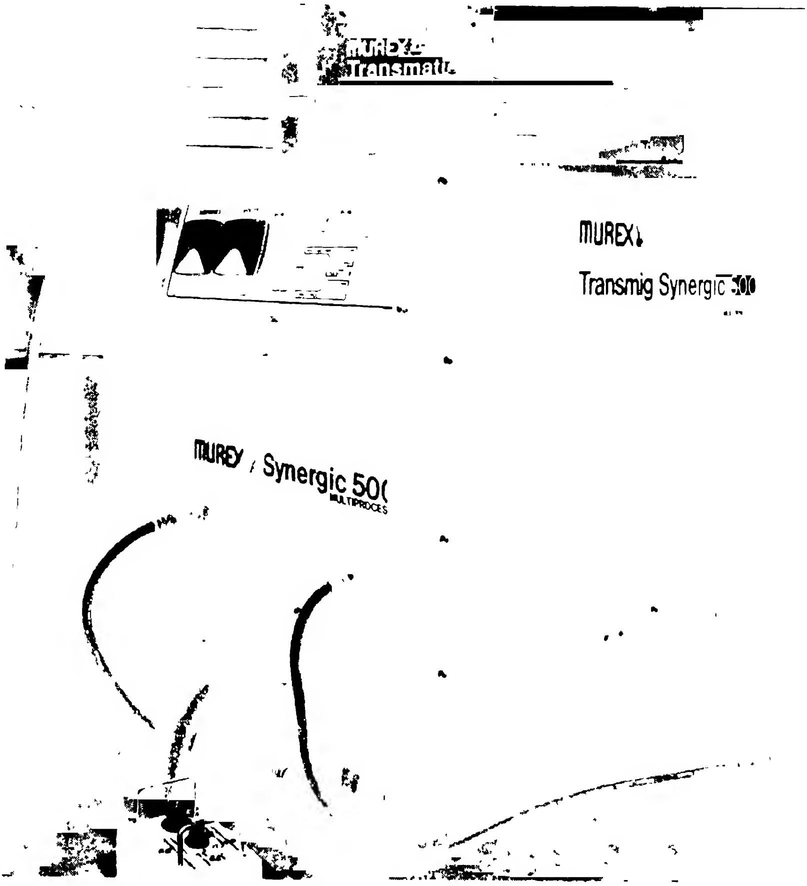


Fig. A13.5. For synergic pulsed MIG (GMAW). See p. 486 for description of unit.

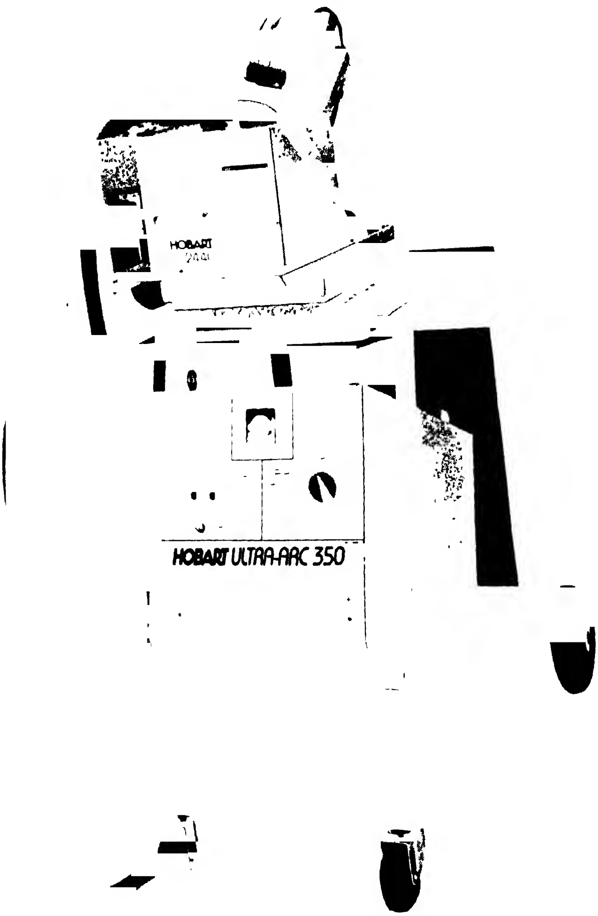


Fig. A13.6. 150 A single phase illustrated (200 A, 300 A and 500 A also available). For the 300 A unit, phase 50–60 Hz 380–415 V inverter unit for d.c. TIG and MMA. Output MMA 5–250 A TIG 5 300 A; arc volts 30, OCV 62. Up and down slope 0 1.5 sec. Arc spot timer. Low and middle pulse frequency with adjustment range 15 85%. Stepless control of current. Smooth shift from welding to crater-fill current. Remote control optional. HF or lift start.

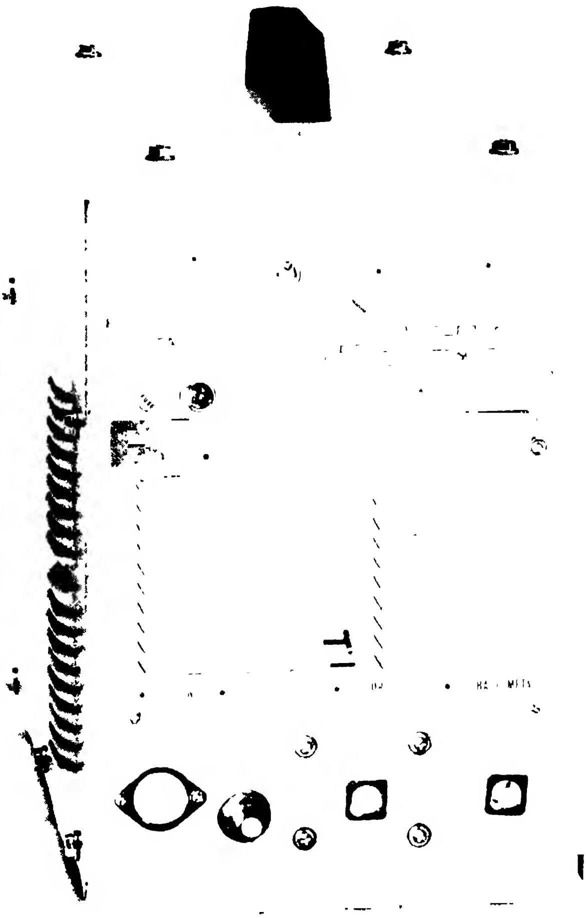
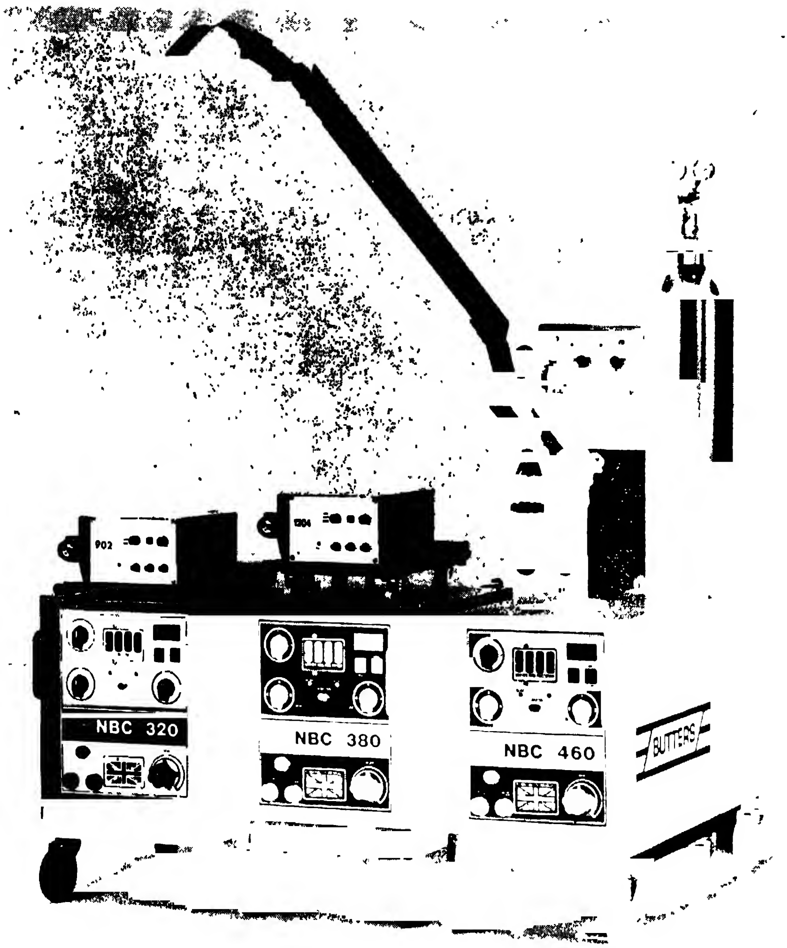


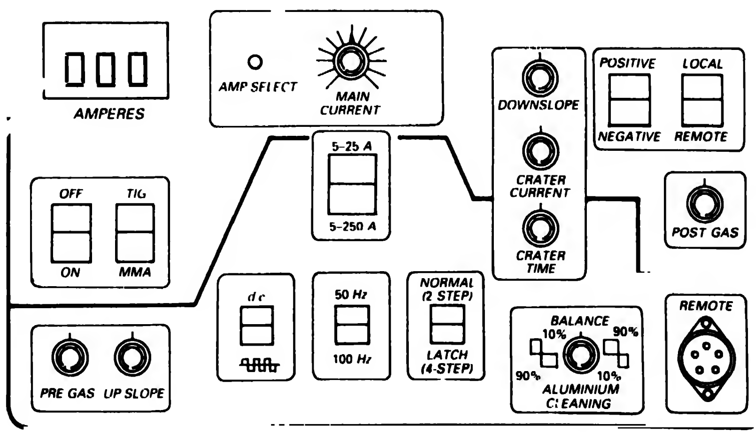
Fig. A13.7 (*opposite*). (*a*) NBC (Butters) MIG power sources to BS 5970 and ISO 9000 in three outputs, 320 A, 350 A and 450 A. Input 3-phase 415 V, 50 Hz. Ratings 10.8 kVA, 13.5 kVA and 17 1 kVA in each case. OCV of each 13–43. Outputs at 60% duty cycle 300 A, 375 A, 450 A; at 100% duty cycle 250 A, 300 A, 350 A, for each unit. Boom supplied if required. (*b*) Ultra TIG 250 square wave. Electronically chopped d.c. with square wave output; solid state control; gas pre and post flow; slope up and down current; craterfill; current settings 5 25 A and 5 250 A; frequency selection 25 450 Hz; cleaning (balanced) 99 1% or 1 99%; latch selector; pulse module optional; digital meters.

)



NBC 320
NBC 380
NBC 460
BUTTERS

(b)



AMPERES
AMP SELECT
MAIN CURRENT
DOWNSLOPE
POSITIVE
NEGATIVE
LOCAL
REMOTE
5-25 A
5-250 A
CRATER CURRENT
CRATER TIME
POST GAS
OFF
ON
TIG
MMA
PRE GAS
UP SLOPE
50 Hz
100 Hz
NORMAL (2 STEP)
LATCH (4-STEP)
BALANCE
10%
90%
ALUMINIUM CLEANING
REMOTE

Fig. A13.8. TIGWAVE 250 a.c./d.c. for a.c. adjustable square-wave TIG welding; d.c. TIG, a.c./d.c. MMA welding with arc force control. Flux cored wire welding with CC CV feeders. Input 220, 240, 415, 500 V, the 415 V model at 35 A, frequency 50 Hz. Output 80 OCV single output 5–310 A, 250 A at 30 V and 40% duty cycle, 200 A at 28 V and 60% duty cycle. Adjustable square-wave control. Crater fill control. Arc force control. Trigger hold which in 'ON' position enables use of torch button when arc is established. Depressing button second time triggers the crater fill function. Optional spot timer. Pre- and post-flow gas timer. See p. 501 for drawing of this power unit.

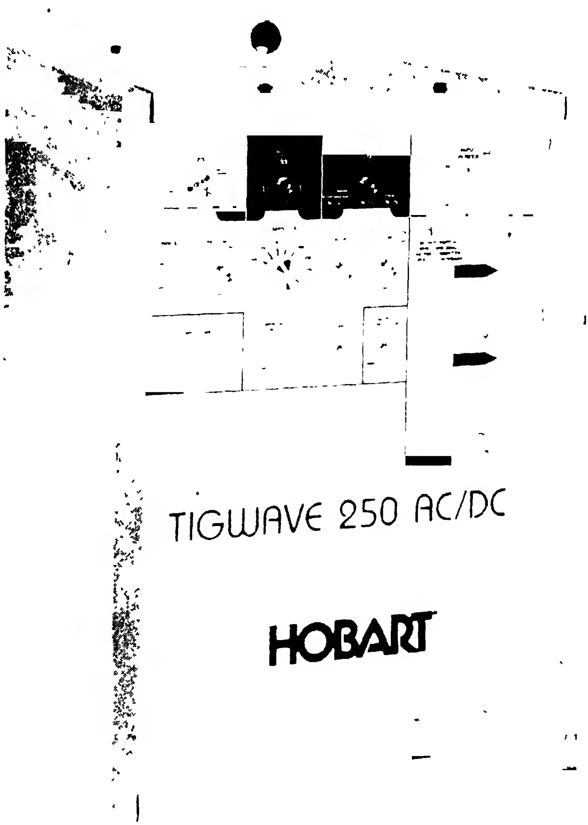


Fig. A13.9. For a.c. and d.c. TIG (GTAW) square wave. See p. 504 for description of unit.

Fig A13.10. Cyber wave 300 A, a.c. or d.c. rated output 300 A, OCV 80. Input 3-phase, voltages 230/460/575. For a.c. square wave TIG, square wave a.c. and d.c. plasma, a.c. and d.c. MMA (stick). For aluminium, magnesium, steel and stainless steel. Auxiliary power 1 kVA. Arc force control. Balance control d.c.e.n. 60–80% for maximum penetration; d.c.e.p. maximum cleaning. Single current range. Solid state program module, calibrated for use with various units, e.g. pulse and arc spot timer, up and down slope, gas prepurge, HF start.

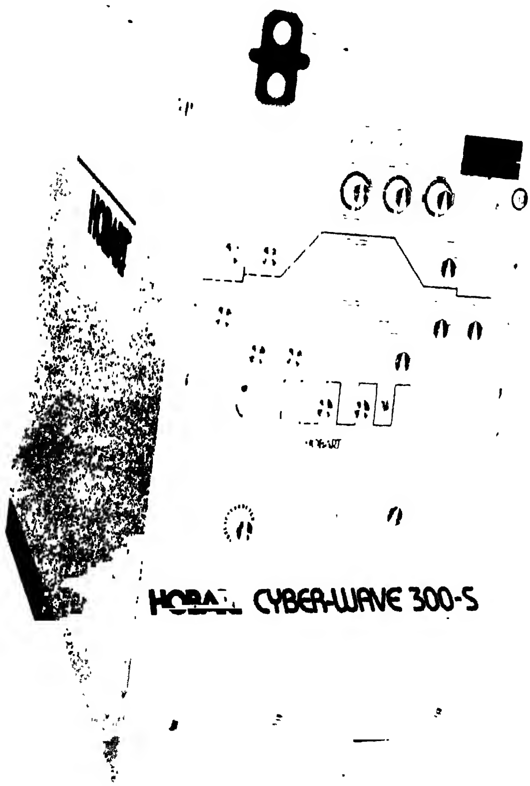


Fig A13.11. PowCon 300 A power source. Inverter, single and 3-phase; suitable for MIG/MAG (GTAW), dip spray and flux cored (FCAW) TIG (GTAW) d.c., MMA (SMAW) and CO_2 processes. Smooth low ripple arc. For 3-phase model, input 380–575 V, with OCV 80. At 100% duty cycle 150 A at 30 V, at 60% duty cycle 300 A at 32 V. Optional extras: pulsed MIG, pulsed TIG. Hand or foot remote control. Generator can be engine-driven if required. Weight 45–48 kg, depending on model.

(*a*)

(*b*)

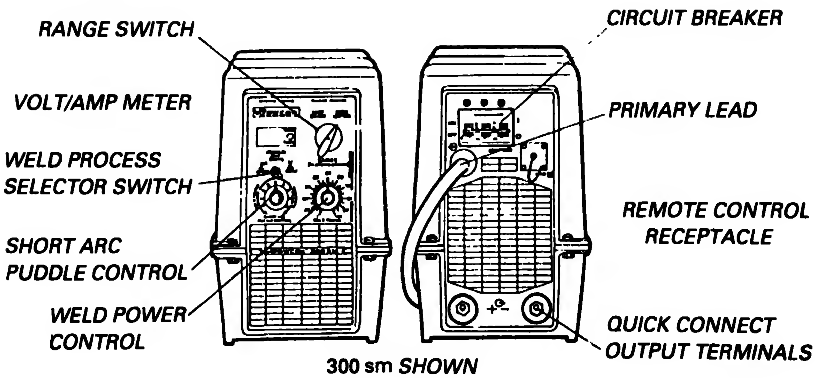


Fig. A13.12. Water-cooled diesel unit. Automatic idle, a.c. and d.c. constant current (CC) output for MMA (stick) and d.c. constant voltage (CV) output for gas, metal and flux-cored arc welding; a.c. TIG by addition of HF unit; 115 and 230 V single-phase auxiliary power for tools etc.

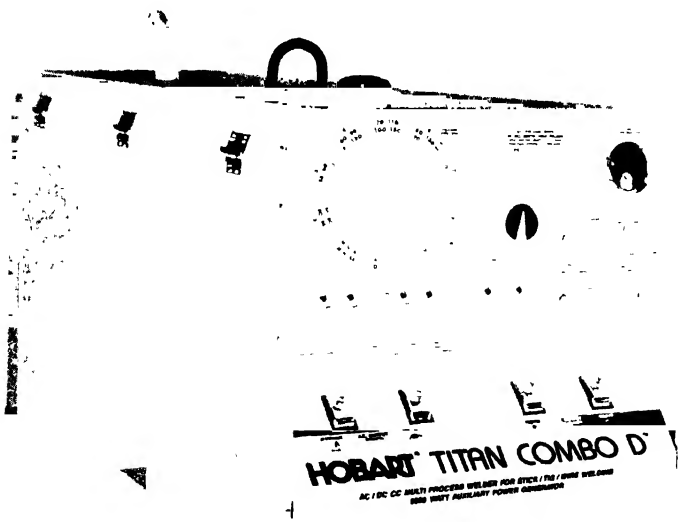
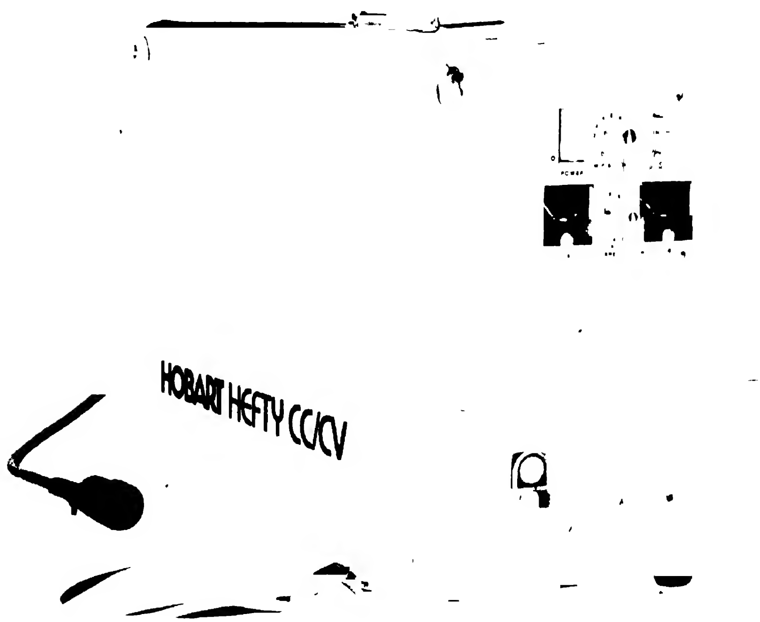


Fig. A13.13. Wire feeder, CC/CV with selector switch. The CV operation controls the wire-feed speed. The CC operation controls the arc voltage. Increase in arc volts means a decrease in wire-feed speed (wfs), one driven roll and one idler roll. Speed of wire 0.127–15.25 m/min. Spool weight 13.6 kg. Wire: tubular 2.0 mm or smaller, solid 1.3 mm or smaller. Weight of unit 11.8 kg. Motor 20 V d.c. permanent magnet motor. Quick connect gun connection. Optional remote control. Suitable for shipyards, pipe-lines, manufacturing, offshore, power plants etc.



Appendix 14

Refraction and reflection

If a ray of light is incident obliquely at a point O on a glass slab and the normal N is drawn at the point O, the light ray is refracted or bent in towards the normal. If i is the angle of incidence and r the angle of refraction to the normal it can be seen that if a ray passes from a rare (air) to a denser medium (glass or water) it is refracted towards the normal (Fig. A14.1*a*). We then have $\sin i/\sin r = \eta$ (refractive index) The value of η is constant for a given pair of media (Snell's law).

Upon emerging from the denser to the rarer medium the ray is refracted away from the normal by the same amount but is displaced by an amount which depends upon the distance travelled through the denser medium (Fig. A14.1*b*).

A stick partly immersed obliquely in water appears to be bent due to the refraction of the light from the immersed end of the stick.

Fig. A14.1 (*a*)

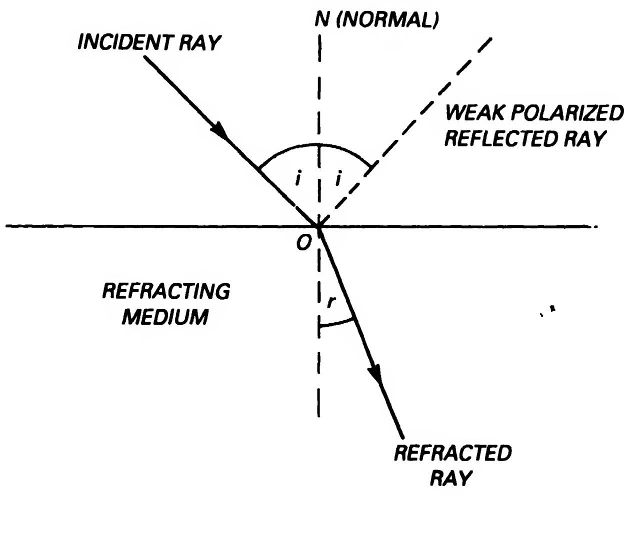
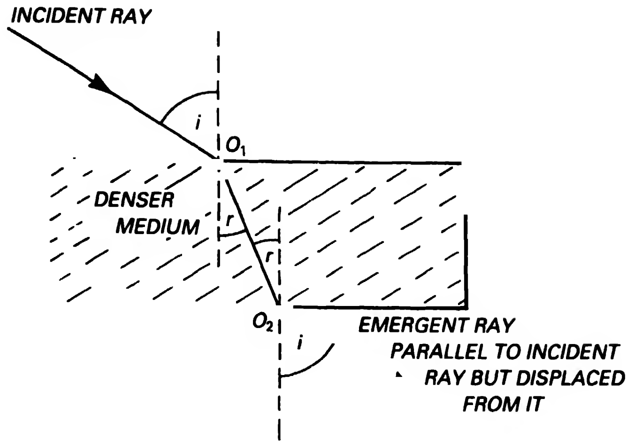


Fig A14.1 (*b*)



Polarization

We have seen that a ray of light is an electromagnetic radiation having two component fields, one electric and the other magnetic, vibrating or oscillating at random, at right angles to each other and at right angles to the direction of travel of the ray.

If the ray is passed through certain substances that allow the electric forces in one plane only to pass through the substance, the emergent light is said to be plane polarized with the electric forces vibrating in the plane of polarization.

Polaroid is the trade name given to a substance of paper-like consistency impregnated with chemicals, which gives an emergent polarized ray when a light ray is passed through it. It is cheaper than the Nicol prism (calcite or Iceland spar) and is supplied in sheets of various sizes. The emergent polarized ray has the electric forces vibrating in the plane of polarization of the sheet.

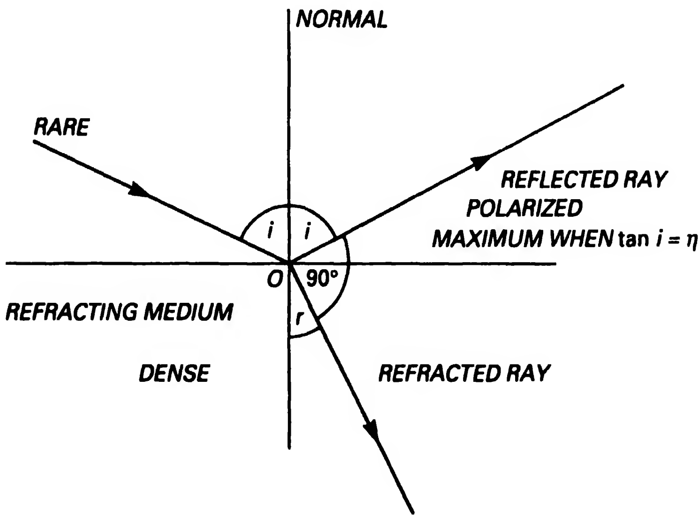
If a second sheet is placed at a little distance from, and parallel to, the first sheet, with its plane of polarization in the same direction, the ray of polarized light emergent from the second sheet suffers virtually no loss. Now rotate the second sheet about the axis of the ray and it will be seen that the polarized ray emergent from the second sheet becomes darker and darker until darkness occurs when the planes of polarization of the two sheets are at right angles to each other. There is now no emergent ray, the polarized ray from the first sheet being completely quenched by the second sheet. The first sheet is termed the polarizer and the second sheet the analyser.

If a solution of a salt is placed in a tube between the sheets, the analyser has now to be rotated through an angle greater than a right angle to the first sheet to obtain darkness. The solution has rotated the plane of polarization of the ray by an amount depending upon its strength, so that by comparing the increased rotation per unit length of various solutions their strengths may be compared.

The eye cannot differentiate between unpolarized and polarized light.

When an unpolarized ray of light is incident at an oblique angle on a surface such as glass or water, part is reflected at the surface and the remainder is refracted into the medium (Fig. A14.2). The reflected component is part plane polarized and this is a maximum when the angle between the reflected polarized ray and the refracted ray is a right angle. This leads to Brewster's law, which states that the angle of polarization at the surface of a medium is the angle whose tangent is equal to the refractive index of the medium.

Fig A14.2



Appendix 15

*Notes on the welding of duplex and super duplex stainless steels**

Duplex and super duplex stainless steels are particularly useful in the petrochemical industry because of their pitting and corrosion resistance. Duplex stainless steels are so called because they have two phases in their microstructure, ferrite and austenite, so they are ferritic–austenitic steels. One of the most common of the duplex steels has 22% Cr, 5% Ni, 3% Mo and 1% N_2, remainder ferrite. The ferrite gives the high tensile strength and the austenite gives the toughness. The latest of these steels is called super duplex stainless steel and has a greater resistance to corrosion and a high pitting resistance. A typical example of a super duplex steel has 25% Cr, 7% Ni, 4% Mo and 0.15% N_2, remainder ferrite. Duplex steels are not sensitive to corrosion cracking but must not be worked above 300 °C, as above this embrittlement occurs. The ferritic–austenitic balance is important as a high ferrite content will cause brittleness and a low one will cause a lowering of resistance to stress corrosion. Contents of 30–70 FN (ferrite number) are normal. The balance between ferrite and austenite depends upon the heat treatment and the composition of the filler metal, the heat input when welding and the interpass temperature. A filler wire should always be used and the result will be a strong and sound weld and HAZ. Welding without any filler rod and excessive dilution of the weld and parent metal produce an excess of ferrite causing the weld metal to be brittle. The interpass temperature must *not* exceed 150 °C (super duplex steels are particularly sensitive to high heat input and the temperature of the interpass runs).

To summarize: high heat input and high interpass temperature give a low cooling rate resulting in brittle phases forming during cooling, whereas low heat input and low interpass temperature during welding give a high cooling rate, resulting in more ferrite and lower toughness resistance. The

* Details of the article and table of consumables by permission of ESAB (UK) Ltd.

gases used for the various processes are: argon or argon–helium mixtures for TIG; argon–oxygen, argon–carbon dioxide or argon–helium–oxygen mixtures for MIG; and argon–carbon dioxide or pure carbon dioxide for flux cored arc welding (FCAW).

When welding duplex steels it is essential to use root gas shielding and this should be argon, or argon with a small amount of hydrogen or nitrogen, and the mixture should be checked to ensure its efficiency. The addition of nitrogen to the backing or shielding gas improves the corrosion resistance while chromium, molybdenum and nitrogen determine the resistance to pitting. The pitting resistance equivalent (PRE) = %Cr + 3.3 % Mo + 16 % N_2. A PRE of 40 is often used as a definition of a super duplex stainless steel. For the estimation of the critical pitting temperature (CPT) ferric chloride is used with a minimum CPT of 40 °C for super duplex, and this may be as high as 60 °C for weld metal that has to stand immersion in sea water (super duplex OK 68.53 is a good example). Welds made in super duplex steels containing small percentages of copper and tungsten often give CPTs of 45–50 °C in this test. This is a good test for sea water corrosion and pitting. The amount of ferrite in the final weld can be estimated by constructing a constitutional diagram using the chromium equivalent along the horizontal axis and the nickel equivalent along the vertical axis. The varying dilutions are indicated by lines on the diagram representing all the compositions of the weld metal that can occur. The chosen dilution is made and other lines drawn to indicate the possible ferrite content of the weld (see, for example, p. 413).

When welding duplex steels the parts should be thoroughly cleaned and brushed with a hand-held brush with stainless steel wires. Use dry electrodes and if necessary warm them before use. Do *not* preheat. The heat input of the run will vary with the plate thickness but must not be too high or too low. Do not strike the arc anywhere outside the joint as this may lead to the initiation of corrosion and cracking. Avoid excessive weaving as this may over-heat the weld. See that the backing gas of pure argon with small amounts of nitrogen or hydrogen is functioning. After welding, clean off all slag and any other foreign matter with a hand-held stainless steel brush. Do not use rotary brushes as they make almost invisible scratches which can lead to corrosion. No post-heating is required, but the part may be solution-treated (see p.130 for description of solution treatment). Do not attempt any stress relief. In other words, the part or welded structure should *not* have any heat treatment.

The arc energy can be calculated in the following way:

$$\text{arc energy (kJ/mm)} = \frac{\text{arc voltage} \times \text{welding current}}{\text{welding speed (mm/s)} \times 1000} \quad \text{(see p. 422).}$$

Consumables for welding duplex and super duplex stainless steel

Composition of base metal (%)	FN	MMA	MIG	TIG	FCAW	SAW
23 Cr, 4 Ni, 0.1 N	30–45	67 50 Rutile 67 53 Rutile	Autrod 16 86	Tigrod 16 86	Tubrod 14 37	Flux 10 93 Autrod 16 86
22 Cr, 5.5 Ni, 3 Mo, 0.15 N	30–45	67 50 Rutile 67 53 Rutile	Autrod 16 86	Tigrod 16 86	Tubrod 14 37	Flux 10 93 Autrod 16 86
25 Cr, 7 Ni, 0.14 N	30–50	68 53 Rutile 68 55 Rutile		Tigrod 16 88		Flux 10 94 Autrod 16 88
25 Cr, 6.5 Ni, 3 Mo, 0.18 N	30 50	68 53 Basic 68 55 Basic		Tigrod 16 88		Flux 10 94 Autrod 16 88
25 Cr, 6 Ni, 3 Mo, 2 Cu, 0.20 N	30–50	68 53 Basic 68 55 Basic		Tigrod 16 88		Flux 10 94 Autrod 16 88
25 Cr, 6 Ni, 3 Mo, 0.7 Cu, 0.7 W, 0.25 N	30–50	68 53 Basic 68 55 Basic		Tigrod 16 88		Flux 10 94 Autrod 16 88
25 Cr, 6 Ni, 3 Mo, 0.7 Cu, 0.7 W, 0.25 N	30–50	68 53 Basic		Tigrod 16 88		Flux 10 94 Autrod 16 88

Note: All electrodes, wires and fluxes are prefixed with the letters OK (e.g OK 67 50); FN is the ferrite number.

As an example, suppose that for duplex steels the arc energy is within the range 0.5–2.5 kJ/mm, and for super duplex stainless steels the arc energy is within the range 0.2–1.5 kJ/mm. Suppose also that a super duplex steel has an arc voltage drop of 20, a welding current of 80 A and a welding speed of 1.5 mm/s. Then from the above formula:

$$\text{arc energy} = \frac{20 \times 80}{1.5 \times 1000} \approx 1.1 \text{ kJ/mm}.$$

This setting would be suitable for both steels as an arc energy of 1.1 kJ/mm falls within the above limits for both steels.

Suppose now, that for a duplex steel the arc voltage drop is 20, with a welding current 100 A and a welding speed of 1.0 mm/s, then

$$\text{arc energy} = \frac{20 \times 100}{1.0 \times 1000} \approx 2.0\ \text{kJ/mm}.$$

This setting of current and weld speed is suitable for duplex steels only, as the arc energy falls outside the figure given for super duplex stainless steels.

Overalloying

Note that in all consumables used for welding duplex and super duplex stainless steels there is more nickel than normal. This 'over alloying' is to help the formation of austenite so that there is not too much ferrite in the final weld metal. The use of a filler material and only a small weave, in addition to the excess nickel, prevents excessive dilution, which would increase the ferrite content and hence the brittleness of the weld.

Appendix 16

Welding fumes: health and safety

The electric arc, used in MMA, MIG–MAG, TIG, and other welding processes, causes visible and invisible fumes to be given off by the melting flux when the arc is burning. These fumes can be harmful if inhaled through the nose and mouth of the welder. The content of the fumes may be either asphyxiating or toxic.

Asphyxiating fumes

Asphyxiating fumes are largely due to the shielding gases used around the arc. They are invisible and produce their effect by displacement of the surrounding air and thus, of its oxygen. (The air which we breathe consists mainly of nitrogen and oxygen, roughly in the ratio of four parts nitrogen to one part oxygen.) Asphyxiation begins when the oxygen content of the air falls below about 18%.

The gases usually used in welding are argon, carbon dioxide, helium and their mixtures. Argon and carbon dioxide are heavier than air (the mixtures are known under trade names). A mixture is selected to give the best welding conditions for a particular process. A simple mixture is the rutile coating for mild steel electrodes in the MMA welding of mild steel. The rutile gives a smooth arc, which is easily managed, but it gives off some hydrogen, which is absorbed by the molten metal and leads to hydrogen cracking under certain conditions of stress. To prevent this the covering is of calcium carbonate ($CaCO_3$), mixed with a little rutile in order to give a smooth and easily managed arc. This mixture now gives off only a little hydrogen (a low hydrogen electrode), which can be used where higher stresses are encountered. The proportion of asphyxiating gas present is generally given in parts per million (p.p.m.) (this can be converted into milligrams per cubic metre of the atmosphere (mg/m^3)).

The mixtures with argon are, like the argon, generally heavier than air

Asphyxiating gases

Asphyxiant	Notes
Argon (Ar)	Non-toxic. Used as a shielding gas, alone or mixed with other gases. Heavier than air and can accumulate at the base of any closed vessel being welded and can form layers at the bottom of the welding operation in a badly ventilated welding shop. Essential to have extraction and circulation of the atmosphere around the welding point.
Helium (He)	Non-toxic. Used generally mixed with other gases (e.g. 50% helium 50% argon). Helium is not produced in this country but is imported from the United States and is therefore much more expensive than argon.
Oxygen (O_2)	Non-toxic but it promotes rapid oxidation especially in the pure state. Atmosphere roughly 4 parts nitrogen to 1 part oxygen (the proportions required by the human body to enable it to function). Used in small quantities (1% to 2%) mixed with argon for stainless steel welding.
Nitrogen (N_2)	Although nitrogen is used for displacing the atmosphere in tanks and pipelines it is not a neutral gas like argon because it forms compounds with other substances. Two of these are produced in welding, namely nitric oxide (NO) and nitrogen dioxide (NO_2), both of which are toxic (q.v.) as nitrogen itself is an asphyxiant. Nitrogen is produced in large quantities as a by-product in oxygen-making plants.

and invisible. They tend to sink to the floor, making an asphyxiating layer which becomes deeper as welding continues. Evaporation and vaporization of the metal from the molten pool rise with the other fumes but are invisible.

*Toxic fumes**

Toxic fumes are made up of very many tiny particles of the flux covering of the electrode, the central core of the flux (if used), and the vapours from the metallic evaporation of the molten metal of the arc; the fumes rise to give the familiar welding fumes. Note that the size of the particles is extremely small. The student should read publications EH40, EH54 and EH55†, together with the COSHH regulations to get a complete

* *Note*. Spatter, which appears as sparks (which are globules of molten metal ejected from the arc), is not classified as fumes.

† All booklets mentioned are published by HMSO and can be obtained from any branch office, or by post from HMSO Books, PO Box 276, London SW8 5DT. They are written by the Health and Safety Executive (HSE) and are available in most libraries, colleges and universities. The full titles are:

HSE Guidance Notes EH40 Occupational Exposure Limits

Guidance Notes EH54 Assessment of Exposure to Fume from Welding and Allied Processes

Guidance Notes EH55 Control, Exposure, Fumes, Welding, Brazing and Similar Processes

picture of this important subject. Booklet EH40 xx (xx indicates the year of printing) gives, in detail, an explanation of the exposure limits. Because the limits are updated each year the values have been omitted from the following table. The student is advised to fill them in using pencil and to keep them up to date. Note that the total fumes inhaled should not exceed 5 mg/m^3.

The following terms are used in EH40:

OES	Occupational exposure standard (given in mg/m^3 or p.p.m. over a given time period).
MEL	Maximum exposure limit (given in mg/m^3 or p.p.m.).
TWA	Time-weighted average. Allowance is made for the periods when the arc is not burning.
ID	Inhalable dust (total dust inhaled).
RD	Respirable dust (quantity of dust that enters the respiratory tract and lungs).
STEL	Short-term exposure limit.

The removal of asphyxiating and toxic welding fumes

If welding is performed outside, there is a constantly changing atmosphere around the welding area, so that the extraction of fumes may not be necessary, but careful assessment should be made to confirm this. If a wind is blowing, however, screens should be set up to prevent the gas shield around the arc being disturbed. If necessary the electrode wire should be flux cored to lessen the effect.

The welding shop should be as large, airy and high as possible. Sometimes there may be long narrow ducts at ground level through which clean air is blown, and similar ducts at ceiling height to enable the polluted air to be exhausted. Even with heated clean air being blown in through the bottom ducts the shop will be very cold in winter time and the heating of the air will add to the cost of welding.

A popular method of eliminating fumes, in use today, consists of a suction unit fitted with a filter, from the suction side of which a large-diameter, fixed, rigid tube is fitted. This tube passes down the shop (well above head height) and over every welding position or bench. Flexible tubes of a similar large diameter are fitted, which reach down to the welding position or bench. At the lower end of the flexible tube a collecting head is fitted (see Figs. A16.1 and A16.2). The tube is sufficiently rigid to remain in any position in which it is placed and the collecting head may be fitted with a magnet to help positioning of the collector. For long

Table of substances in fluxes which produce toxic fumes

Substance	Notes	OES mg/m³	TWA 8 h STEL	MEL mg/m³	TWA 8 h STEL
Aluminium and its alloys, aluminium oxides Al_2O_3, $Al(OH)_3$, $Al(OOH)$)	Fumes are produced when welding aluminium and its alloys. Inhaling the fumes over long periods may affect the respiratory tract.				
Cadmium and its compounds, cadmium oxide fume	These are highly toxic and are generally formed when welding articles that have been cadmium plated. Clean off in the areas to be welded.				
Calcium, calcium oxide, calcium hydroxide, calcium carbonate, calcium silicate	Though non-toxic, fumes may irritate the respiratory tract when in large concentrations.				
Carbon dioxide	Present mixed with many types of shielding gases. It is mildly toxic and, being slightly heavier than air, sinks to the base of closed containers when welding. With the other gases it acts as an asphyxiant.				
Carbon monoxide	Very toxic. Small amounts are formed when CO_2 is present as a shielding gas.				
Chromium and its compounds, chromium II, chromium III (trivalent), chromium VI (hexavalent)	Fumes are produced when welding stainless steel and other alloys with a high chromium content. These are all toxic and those of chromium III and VI may be carcinogenic.				
Copper and its compounds, fumes, dust and mists	Toxic fumes are produced when welding copper. Most welding wires for welding steel by the MIG process are copper coated to prevent rusting, but produce very few copper fumes.				
Iron and its compounds, iron oxide fumes Fe_2O_3, iron salts	Only slightly toxic and found when welding steels. Welding may cause deposits upon the lungs.				

Table continued

Substance	Notes	OES mg/m³	TWA 8 h STEL	MEL mg/m³	TWA 8 h STEL
Lead and its compounds, lead in the atmosphere (lead in the air is taken as standard)	Very toxic. Large amounts of fumes are produced when welding heavily lead-painted articles (clean off paint where required). Fumes are given off when lead is welded. These are very toxic.				
Magnesium, magnesium oxide (MgO)	Formed when welding high magnesium content aluminium alloys, which work-harden.				
Manganese and its compounds	Fumes are toxic. Manganese is used as an alloying element in steel making, 12 14% manganese steel work-hardens and is work resistant. Fumes affect the nervous system and respiratory tract.				
Barium (soluble) and its compounds	Highly toxic and found in some flux cored wires.				
Nickel and its compounds, soluble compounds	Present as an alloy in many steels and in stainless steel as a major alloying element. Fumes are very toxic. Affects the respiratory tract and produces metal fume fever. May be carcinogenic.				
Silicon, silica (SiO_2)	Non-toxic. Contained in some fluxes in core or covering. Little effect on welding fumes as only small amounts are formed.				
Zinc and its compounds, zinc oxide (ZnO), zinc chloride ($ZnCl$)	Toxic. Fumes of zinc oxide are given off copiously when welding galvanized articles, the coating of which is zinc. Grind off the coating from areas to be welded.				

Fig. A16.1. Practically all fumes are collected at this distance.

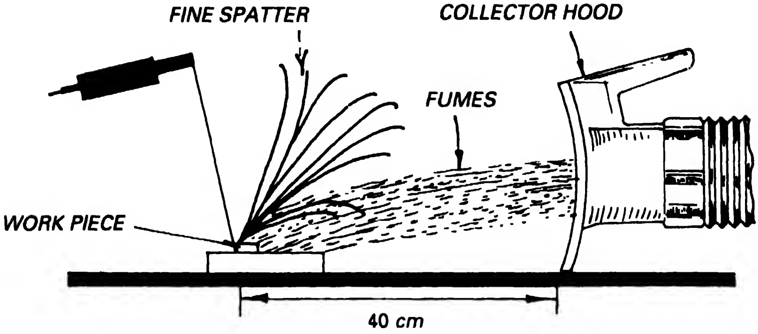
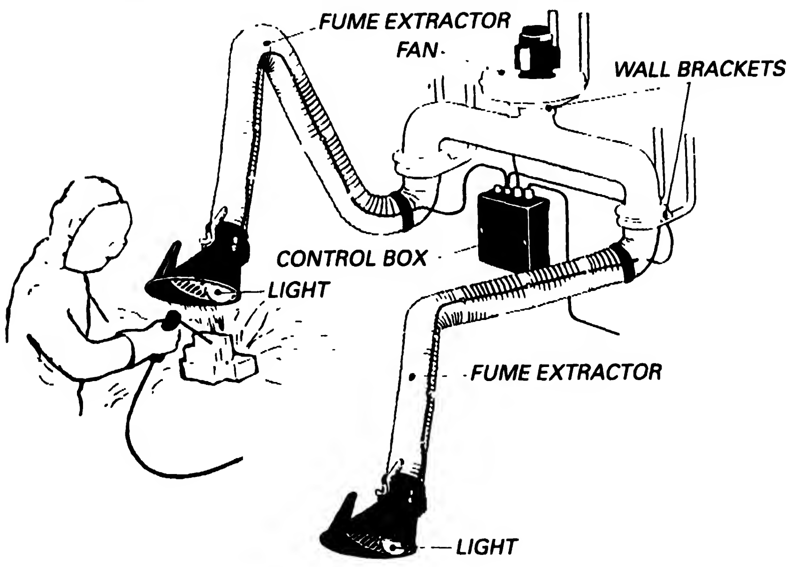


Fig. A16.2. Twin fume extractors with fan, light and control box.



extensions from the overhead tube, the flexible tube may be fitted with several jointed or articulated arms passing inside the tube. These arms are a great help in positioning the collector in cases on the shop floor when the cantilever effect is maximum. The collecting head may be fitted with a shutter, hand-operated from outside the head, so that an operator can switch off the suction without affecting other welders on the same circuit. In addition, there may be a protected electric light to assist the operator in positioning the work. For larger articles and fabrications a portable unit can be used.

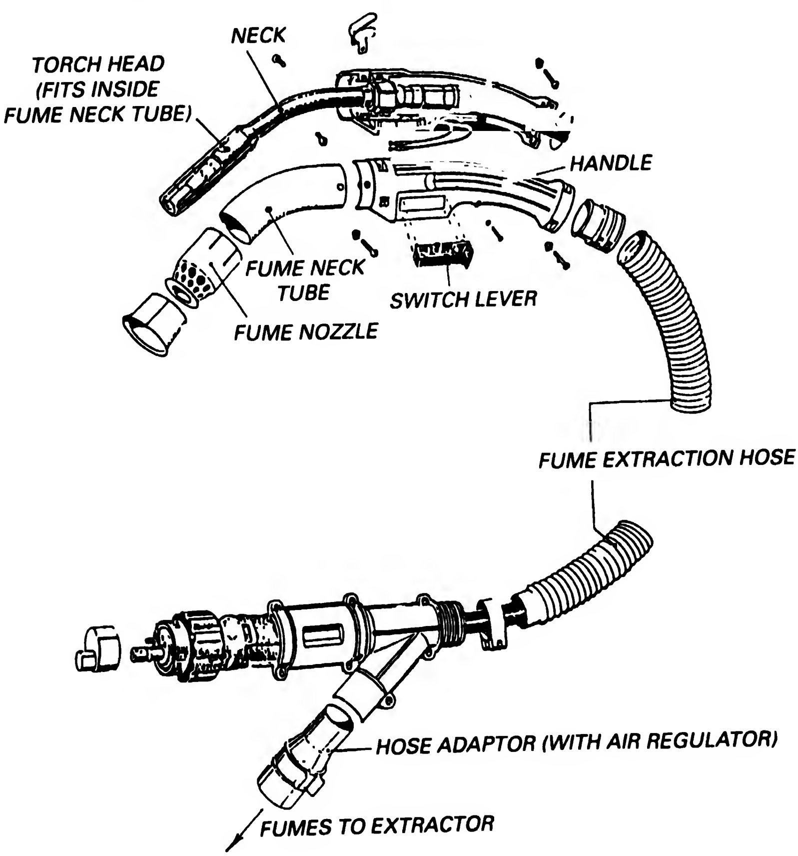
The filter, starting unit and electric motor are all mounted on wheels and

can easily be moved around. A large-bore flexible tube is fitted to the suction side of the unit and the collector is positioned by the welder, the collector being above weld level and as close as possible to the weld without impairing the work of the welder. The extracted air is filtered to remove the fumes, and the air is then returned to the atmosphere.

For this kind of work the suction rail method is useful. This consists of a fixed large-diameter tube fitted with rails. A collector on the rails and running on wheels is pulled to cover any desired point in the fabrication, and the tube on the collector delivers the air and fumes directly into the suction tube. The clean air exhausts to the atmosphere no matter where the trolley is placed.

In some cases, when MIG welding, the gun may incorporate fume-collecting ducts. In the body of such a gun, towards the lower end, are some holes or ducts (see Fig. A16.3). The fumes are sucked in through the holes,

Fig. A16.3. MIG gun with built-in fume collector (Murex).



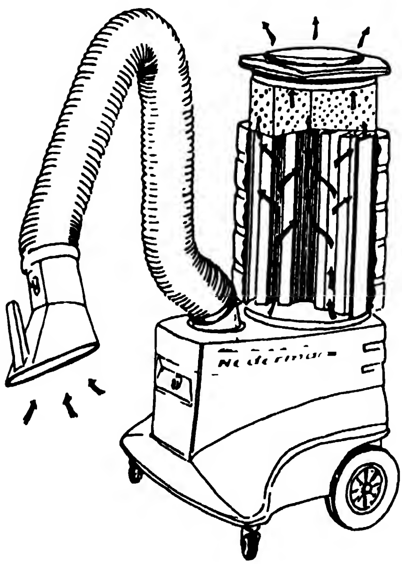
up the bore of the gun and are quite separate from the shielding gas and water-cooling (if any) supply. Higher up the gun is an angled unit attached to the suction tube of the fume-cleaning unit. The fumes are collected as they are made, and collection does not interfere with the shielding gas supply. The fumes pass up the gun and are filtered and exhausted as described earlier. Note that these guns are available only for MIG welding.

Electrostatic precipitation can be utilized where it is inconvenient to install a fixed collector. Upon entering the precipitator, fume particles are charged electrostatically and then pass through an insulated sleeved tube to plates of opposite polarity to that of the particles. They are deposited on the plates, which are part of the filtering elements, and the air issuing from the unit is fumeless and is returned to the atmosphere. Fig. A16.4 shows a Sectional view of a filter.

Efficient extraction of fumes is essential to the long-term health of the welder, as it may be many years until the effects of fumes inhaled over a long period are apparent. Almost all the toxic substances in the table above have a long-term effect on the respiratory tract and lungs, and in time seriously affect the health of the operator. Therefore, take all precautions possible:

> Never weld with head and helmet directly in the path of rising fumes.

Fig. A16.4. Mobile unit with filter. Arrows show passage of fumes through the replaceable paper filter. In the electronic model an additional motor cleans the filter elements and indicates when the main container needs emptying.



Never use a flat shield.

Use a head shield that protects the face, head-sides and neck.

Use a filter glass of the deepest shade compatible with the weld being performed.

Wear gloves to protect hands and wrists from the harmful effects of UV rays.

Never weld with the sleeves rolled up.

Protect the body skin by covering it.

However carefully employers safeguard the health of their welding operators in the welding shop or fabricating area within the COSHH regulations and the HSE recommendations, it is finally up to the welder to safeguard his or her health, by following these regulations regarding toxic fumes and asphyxiating gases. Figs. A16.1–A16.4 should make some of the apparatus for toxic fume removal quite clear.

Free information booklets on the hazards to health from welding fumes are provided by the makers of the electrodes and gas suppliers, for example:

Air Products Plc, 4th Avenue, Crewe, Cheshire

BOC Ltd, Guildford, Surrey

Eland Group Butters Ltd, Hartlebury, Worcestershire

Murex Ltd and ESAB Ltd, Waltham Cross, Hertfordshire

Nederman Ltd, Bamber Bridge, Preston, Lancashire

Oerlikon Welding Ltd, Hayes, Middlesex

Welding Manufacturers Association, Leicester Street, London WC2

Appendix 17

*The generation of acetylene (low and medium pressure) and purification**

The generators are usually of two types: (1) water to carbide (low pressure); (2) carbide to water (medium pressure).

Low-pressure system

Fig. A17.1 shows a typical water to carbide generator of the 'rising bell' type. The outer vessel is filled with water and all taps are turned off. The rising bell *R* is down, and the cross bar *H*, fixed to the rising bell, holds the

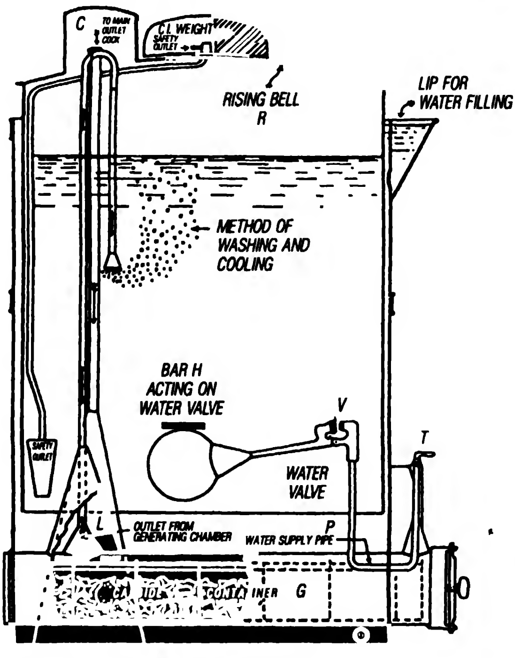


Fig. A17.1. Low-pressure generator.

*See Chapter 13 for oxy-acetylene welding.

ball arm down. A charge of carbide is placed in the container *G* (there may be one, two or three such containers, according to the capacity of the plant), and the front tap *T* is turned on. Water flows down the pipe *P* and enters the carbide chamber. Gas is generated, and leaving by the duct *L* enters the rising bell, being washed and cooled as it passes through the water. The rising bell rises and lifts the cross bar *H* up, and the ball arm can now rise and shut off the valve *V*, preventing further water being admitted to the carbide. The acetylene is led out by the pipe *C*, passes through a condensing chamber where any excess water is trapped, and then is led into the purifier. Generation is completely automatic, and the fact that the storage chamber is separated from the generating chamber by a column of water adds to the safety of the apparatus.

Medium-pressure system

Fig. A17.2 illustrates a generator of the carbide to water type. The carbide is contained in the hopper *C*, and falls into the water contained in the

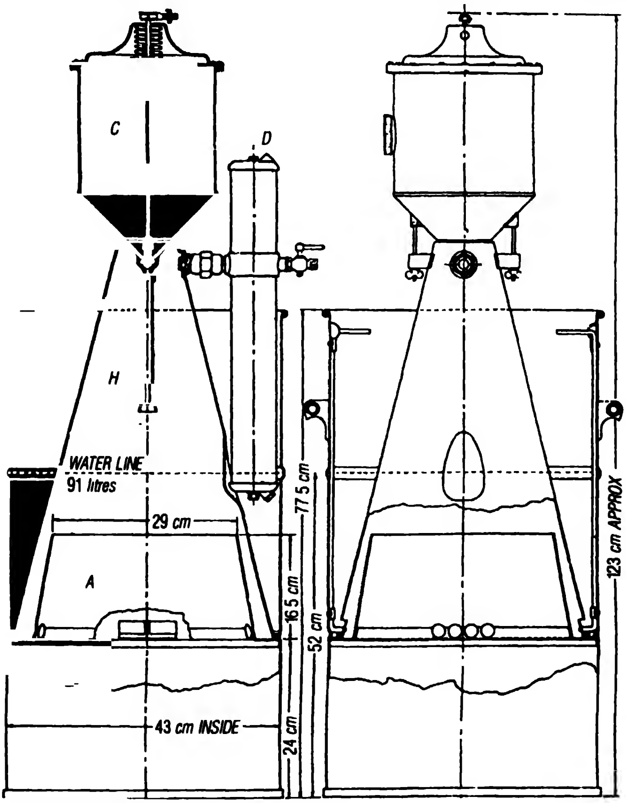


Fig. A17.2. Medium-pressure generator.

container *A*, through the cone feed valve. The gas produced forces a certain volume of water out of the gas-holder space into the water container. This creates the necessary working pressure, and at the same time, pressure is exerted on the inside of the flexible diaphragm at the top of the hopper, to which a cone feed valve is fixed, and this lifting action closes the valve.

When gas is used a slight reduction in pressure occurs, and the valve opens, letting in more carbide and generating more acetylene. This design is sensitive in operation and responds to a large or small demand of gas without overmaking or waste of gas.

The dehydrating tube (*H*) prevents condensation reaching the cone feed valve at the base of the hopper. Should a back fire occur and cause a displacement of the water seal, the liquid passes temporarily into an upper chamber and, when the back pressure has subsided, drains back into the normal position again. This is the function of the resealing type hydraulic valve *D*.

Purification of acetylene

It is important that acetylene used for welding should be free from chemical impurities which are detrimental to the welding process.

Certain impurities are always present in crude acetylene, but the amount depends upon the conditions under which the gas is generated. If generation takes place in a well-designed generator which has a capacity well above the maximum demand likely to be made upon the plant, the gas will be produced at a low temperature and impurities will be kept to a low limit. If, on the other hand, the gas is produced too quickly, considerable heat is generated, which increases the proportion of impurities in the gas. The quality of the carbide also has a great effect on the purity of the gas produced. Only carbide which conforms to British Standard Specification No. 642/1935, both as to gas yield and purity should be used.

The impurities in crude acetylene consist chiefly of ammonia, hydrides of phosphorus, sulphur and nitrogen, and there are also present water vapour and particles of lime.

A good acetylene generator embodies arrangements for thoroughly washing the gas, and this process will remove most of the ammonia and some of the sulphuretted hydrogen impurities, but to remove the phosphoretted hydrogen it is necessary to pass the gas through suitable chemical purifying materials.

A diagram of a typical purifying vessel is illustrated in Fig. A17.3. From this drawing it is clear that gas enters the purifier at the base. After passing through a layer of pumice, which serves to precipitate water vapour, the gas percolates

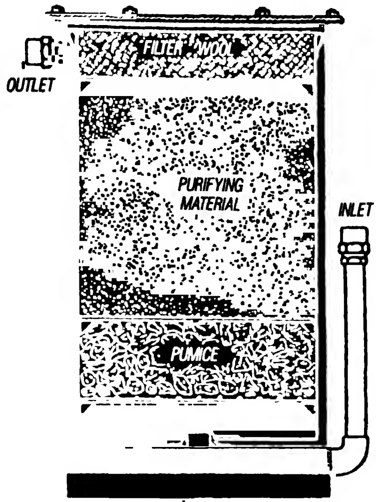


Fig. A17.3. Acetylene purifier.

through the purifying material and finally through a layer of filter wool, whence it passes into the service. The filter wool collects any particles of lime or of the purifying material itself and prevents them being carried forward with the gas. Supporting grids are provided for each layer of purifying material to prevent undue loss of pressure, and there is a tap for removing any condensation. To facilitate recharging, the inner receptacle can be lifted right out, and the simple construction of the apparatus ensures easy and efficient operation.

To obtain the best results from the purifying material it should be packed evenly and carefully. There should be a total depth of about 254 mm, and the purifier should have a diameter sufficient to avoid any restriction of gas flow.

A satisfactory purifying material must conform to the following conditions. It must:

(1) have a minimum corrosive action upon the material of the purifying vessel;
(2) be non-inflammable, non-explosive, and incapable of forming explosive compounds during use;
(3) be without action upon the acetylene itself under normal conditions;
(4) be of a nature to offer the minimum resistance to the flow of the gas, consistent with adequate contact with the gas;
(5) be capable of absorbing a considerable amount of moisture from the gas without decreasing its purifying power, or increasing its resistance to the flow of the gas;

(6) show a pronounced colour change to indicate when the purifying properties are exhausted.

To conform to condition (4), it is the general practice to impregnate a highly porous material, such as good quality kieselguhr or powdered pumice, with a solution of suitable materials capable of oxidizing the impurities, and at the same time satisfying other necessary conditions. Active oxidizing agents used for acetylene purification can be divided into three main types:

(a) bleaching powder, or hypochlorites;
(b) chromic acids;
(c) salts of ferric iron.

The use of materials of the first type has long been discontinued owing to the danger of explosive interaction between acetylene and the chlorine evolved from the hypochlorites.

Very satisfactory purification can be obtained from the best materials of the second type, but the following objections to their use may be raised:

(a) chromic acid is corrosive;
(b) under normal purifying conditions chromic acid reacts to some extent with acetylene itself, forming acetaldehyde and acetic acid. Some of the latter may be carried forward by the gas and cause corrosion in the pipe lines and blowpipes.

Materials of the third type satisfy all requirements, and when appropriate metal salts are present, such as catalysts, these purifying materials may be regenerated by exposure to air. With this type of purifying material the initial purifying value is as high as that of the chromic acid class, and it has the advantage of being able to be used several times by carrying out the regenerative process described.

The normal method of testing acetylene to ascertain whether it is being efficiently purified is to hold a silver nitrate test paper (a piece of filter paper soaked in a solution of silver nitrate) in the stream of gas for about 10 seconds. If the acetylene is being properly purified, there will be no trace of stain on the silver nitrate paper.

Hydraulic back pressure or safety valve

When acetylene is supplied from a low-pressure generator, a back-pressure valve must be used to prevent oxygen or air entering the acetylene generating plant or supply line and thus creating an explosive mixture. Each blowpipe supplied from the main acetylene supply line should have its own back-pressure valve. A typical valve is shown in Fig. A17.4.

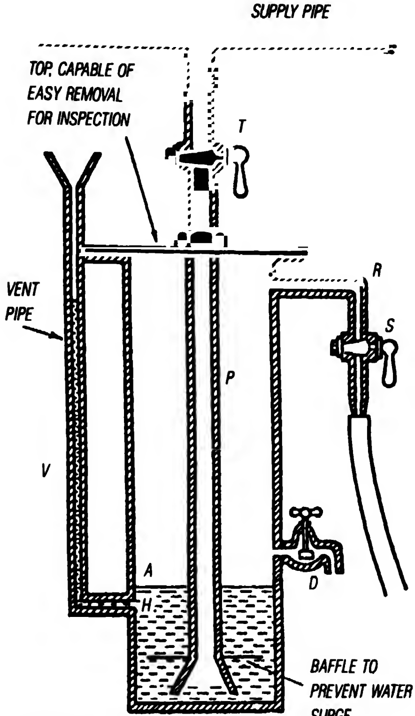


Fig. A17.4. Back-pressure valve.

The cylinder can be filled with water via the vent pipe *V* up to the level of the drain cock *D*. Gas is led from the main line through the tap *T*, down the centre pipe *P* and bubbles through the water, eventually leaving by the tube *R* and tap *S*. The pipe *P* has a baffle plate fixed to its lower end. In the event of a back fire, or should a back pressure be set up in the blowipe line, the water level *A* is depressed and water is forced up the vent pipe until the hole *H* is exposed. The burnt gases in the case of a back fire, or the gases under pressure, thus pass up the vent pipe inio the atmosphere and are prevented from getting into the supply line and generator. Since a valve is fitted in each blowpipe, a back fire from one pipe cannot flash back into another.

The water level should be checked each day and the cylinder filled to the level of the drain or levelling cock. Excess water can be drained off at this point and at intervals the valve should be dissembled for cleaning and inspection of the inlet pipe for cracks and fractures, as these would render the valve inoperative. Anti-freezing mixtures can be used, if the valve is in an exposed position, to prevent freezing in frosty weather. Glycerine added to the water is a good remedy, the more glycerine that is added, the lower the temperature at which the mixture will freeze.

Appendix 18

Forge welding

Because of the greater quantity of heat required for forge welding, it is necessary to have the following equipment: a blacksmith's hearth with a suitable (possibly water-cooled) tuyère and an air blower (either hand-operated or power-driven), an anvil and associated tools, and a supply of suitable fuel (coke, coal or high-grade charcoal). The hearth and tools can be made in a reasonably well-equipped small workshop, some details are given on pp. 811–12.

Before attempting to carry out this type of welding it is essential that the person involved should have mastered the basics of hand forge work in general.

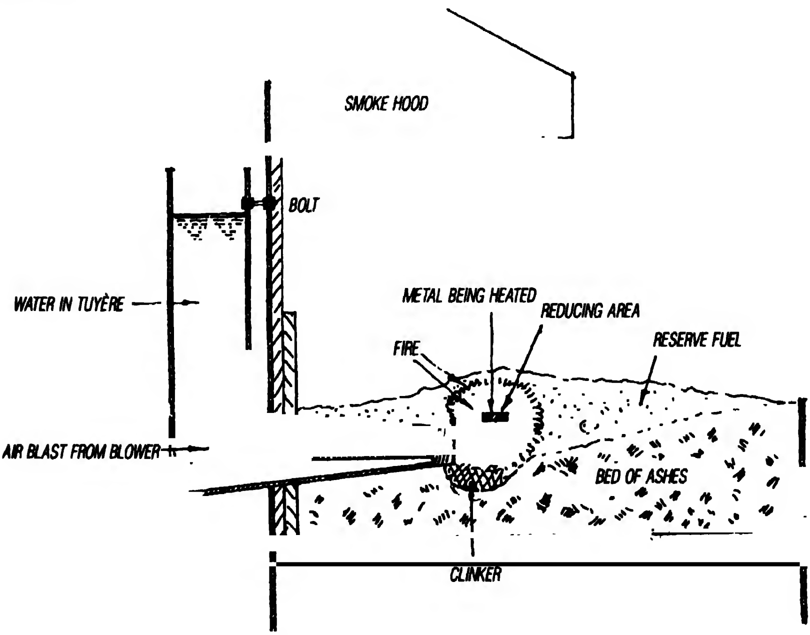


Fig. A18.1 (*a*). Various parts of hearth.

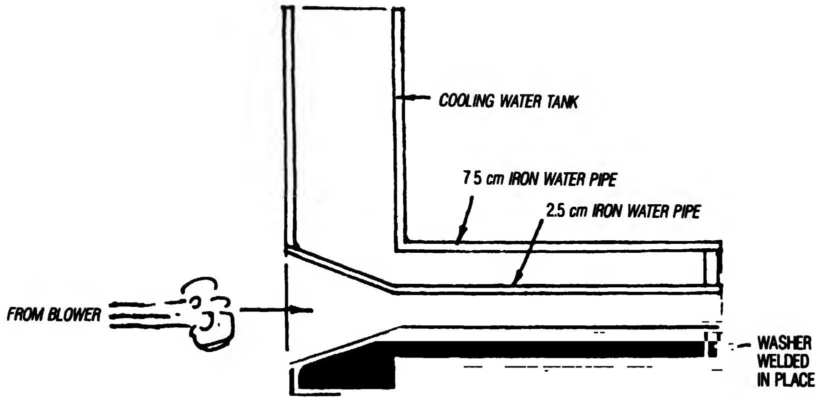


Fig. A18.1 (*b*). Cooling tank and tuyère.

A typical side blast hearth is shown in Fig. A18.1 (*a*), where the relationship of the water-cooled tuyère to the hearth can be seen. The air blast to the fire is conducted through the tuyère to the fuel, while the tuyère itself is kept at a lower temperature by the water jacket (details of a simple fabricated water-cooled tuyère that could be made in a small workshop are shown in Fig. A18.1 (*b*)). The water circulates by convection. Where a powered blower is used, a simple slide valve is situated between the blower and the tuyère so that the amount of air fed to the fire can be controlled. The fire is lit using paper and sticks of wood. When these are well alight fuel is fed onto them and a slight air blast is introduced. More fuel is added and the air blast increased until the fire is the size required for the work in hand. Increasing the air blast increases the rate of burning of the fuel and thus raises the temperature of the fire, which can reach 1500–1600 °C. Welding temperatures for iron and steel can be reached (e.g. 1350 °C for mild steel).

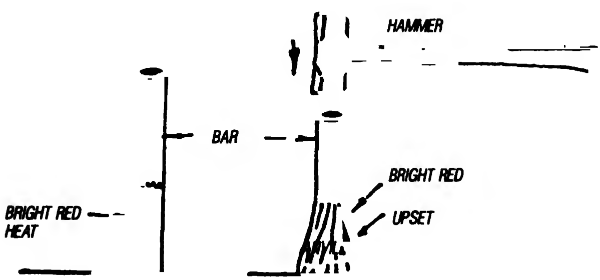


Fig. A18.2. Upsetting.

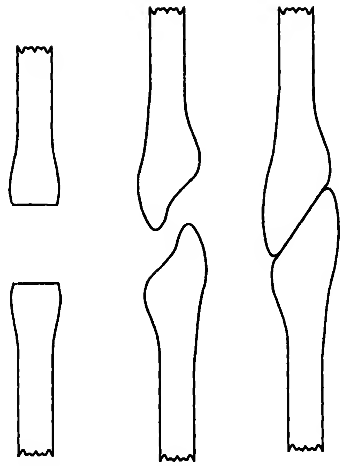


Fig. A18.3. Scarf butt weld.

Specimens to be welded are heated to bright red or yellow and upset, as in Fig. A18.2, to allow for scarf preparation of the ends to be welded and to allow for losses in the fire and subsequent hammering. Suitable scarf preparation is shown in Fig. A18.2 and the operation used to achieve this in Fig. A18.3.

After this preparation the two pieces are returned to the fire and brought to a brilliant white heat, which matches the hottest part of the fire. Some sparks will be given off but these are incidental, and not a true indication of the welding heat. When so heated the parts are rapidly removed from fire to anvil, positioned as in Fig. 18.3 (*c*), and rapidly hammered together. Oxide is expelled from between the scarfs and the clean hot metal forced into close contact, and at this high temperature is welded, forming a completely homogeneous joint. Subsequent forging can bring the pieces to their original size and section. This series of operations requires much practice to achieve good results.

Welding a chain link

A pre-calculated length of suitable material is cut from a bar, the centre section heated to a bright red heat and bent into a 'U' shape with the sides of the 'U' of equal length. The open ends of the 'U' shape are reheated to a yellow heat and then prepared for welding by holding each in turn over the edge of the anvil at an angle of about 45° to the edge; then with hammer blows, a small amount of the metal is thinned down to produce an 'ear'. The work is turned over and the same operation carried out on the second end.

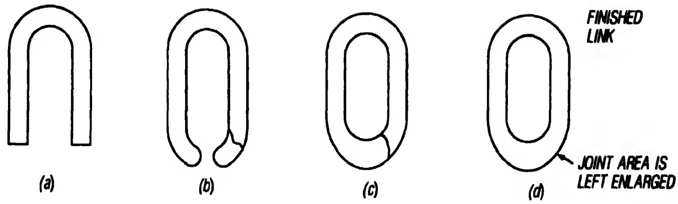


Fig. A18.4. Forge-welded chain link.

Reheating if necessary, these ends are now bent so that the 'ears' cross over and overlap the thick sections and are brought into close contact, forming a 'scarfed' preparation which will allow the joint to be hammered together without slippage occurring. The weld is now carried out by holding the link in properly shaped tongs which will allow manipulation of the work without slippage, and heating the prepared ends to a brilliant white heat (restricting the heat to the ends of the link as far as is possible). At this temperature a few sparks may be given off from the surface of the metal. When the welding temperature has been reached the link is rapidly removed from the fire, placed flat on the anvil face, and firm, rapid hammer blows delivered across the joint, applying pressure which forces out surface oxides, bringing the clean faces of the metal into close contact.

The work is then transferred to the bick (or beak) of the anvil, the weld completed and the link shaped to the final curvature (see Fig. 18.4). A fabricated anvil is shown in Fig A18.5.

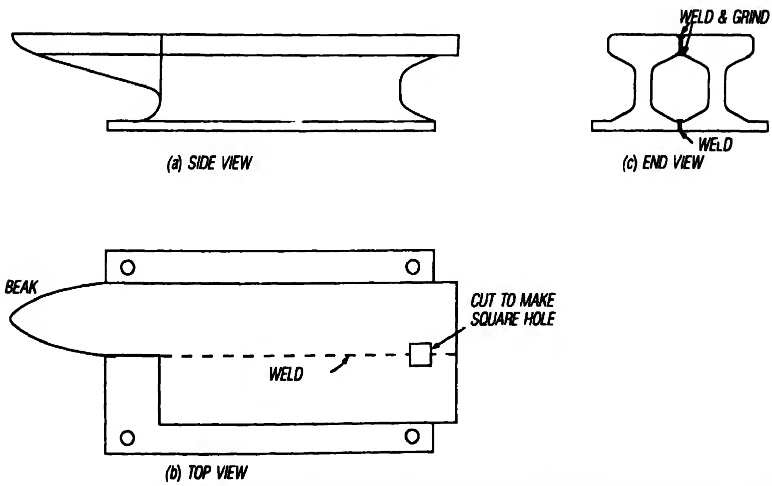


Fig. A18.5. Anvil made from two pieces of flat-bottom railway line about 600 mm long, welded and cut and shaped together.

Welding a 'T' piece to a straight section

The weld preparation or 'scarf' is, in this example, a 'cleft' or split type. The straight section is heated to a yellow heat in the position of the weld and 'upset' to increase its thickness. The increase in thickness must be enough to allow for wastage in the fire and reduction of section due to hammering. The actual amount will depend upon the skill of the smith. The heat can be restricted to the required position by selective cooling. This upset is worked to one side, and a lip, tapered in section, is drawn out from the workpiece. The other piece is also upset and a cut made in the end, the sides of the cut opened out and tapered to form two flat points forked away from each other. While hot, this preparation is made to fit tightly over the preparation on the other bar. Both pieces are now brought to a full welding heat at the position of the scarf preparation. See Fig. A18.6. Preferably with assistance, the longer piece is placed with the scarf vertical and the cleft piece placed over it and hammered down into position. As soon as the pieces are felt to stick together, after the expulsion of oxides, the work is rapidly turned onto its side and the cleft sides of the preparation hammered to complete the weld. The work is then forged to the size and section required and the angles adjusted. This preparation can be used for either round- or square-section material.

There are many variations of weld preparation used for a wide range of applications but all must provide simple, rapid and slip-free positioning of the parts to be joined, allow access for the hammer or other tools, and allow additional material so that forging can be carried out leaving adequate material in the joint.

Scarf butt weld

Upset the ends of two suitable pieces of bar (round or square). Scarf the ends as shown (Fig. A18.3) and ensure a snug fit with each other. Bring

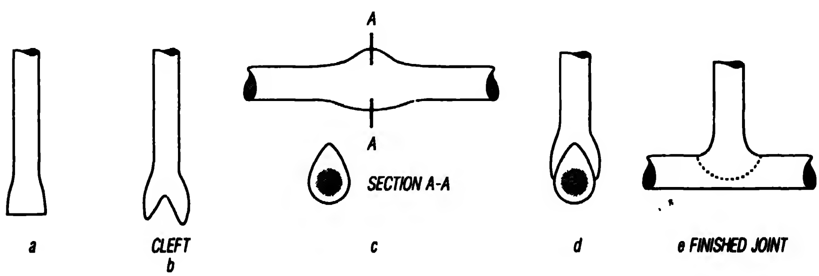


Fig. A18.6. Right-angle forge welded joint.

both to a brilliant white welding heat, rapidly place one on the flat of the anvil, position the other over and onto it (making sure that the scarfed ends are in their correct position), and rapidly hammer them together, turning to allow hammer blows on both sides to expel oxides and bring the surfaces into close contact. The work is then forged to the required size and section. It is advisable to have the services of a helper for this type of weld.

Cleft scarf butt weld

This type of joint is usual for heavier sections of metal. Both pieces are heated and upset on their ends. One has a flat rather abrupt point forged onto it while the other is split and the legs formed by the split are tapered to form two flat points between which the first piece will fit snugly. Both are brought to full welding heat, the helper takes the cleft piece and lays it across the anvil and the other piece is positioned and rapidly hammered into it. As soon as the pieces are felt to stick together the work is turned and the cleft scarfs hammered into the mass of the joint. With the weld completed the work is forged to the required size and section. See Fig. A18.6.

Note: tapping the heated metal onto the anvil before welding helps to remove surface oxide.

Forge cleft T-shaped joint

This joint is shown in Fig A18.6 and is self-explanatory.

Use of mined coal for forge work

Where mined coal is available but not commercially coked for industrial purposes, suitable coal can be used directly onto the blacksmith's hearth. This requires additional fire management because the coal must be converted to coke on the hearth during forging operations and prior to being fed into the heart of the fire.

Suitable coal is soft and bituminous with a low ash and sulphur content. For convenience it is broken up into small granules, such as would pass through a 5–6 mm sieve mesh or smaller. In fact, coal dust can be used. The fuel is placed on the hearth in a semicircular mound, close to and around the fire, leaving the front open to allow access to the fire for workpieces. This 'reserve' of fuel is well wetted with water and kept moist. The heat from the fire converts the face of the coal to coke, which is then raked onto the fire as needed, thus exposing more coal to the effects of the heat; this, in turn, is

converted to coke for use on the fire. Forward thinking is important to ensure that sufficient fuel is coked to keep the fire well fuelled for the work in hand, and to ensure that a small reserve of coked coal is ready for later use when forging is discontinued for any length of time, such as overnight. See Fig. A18.7.

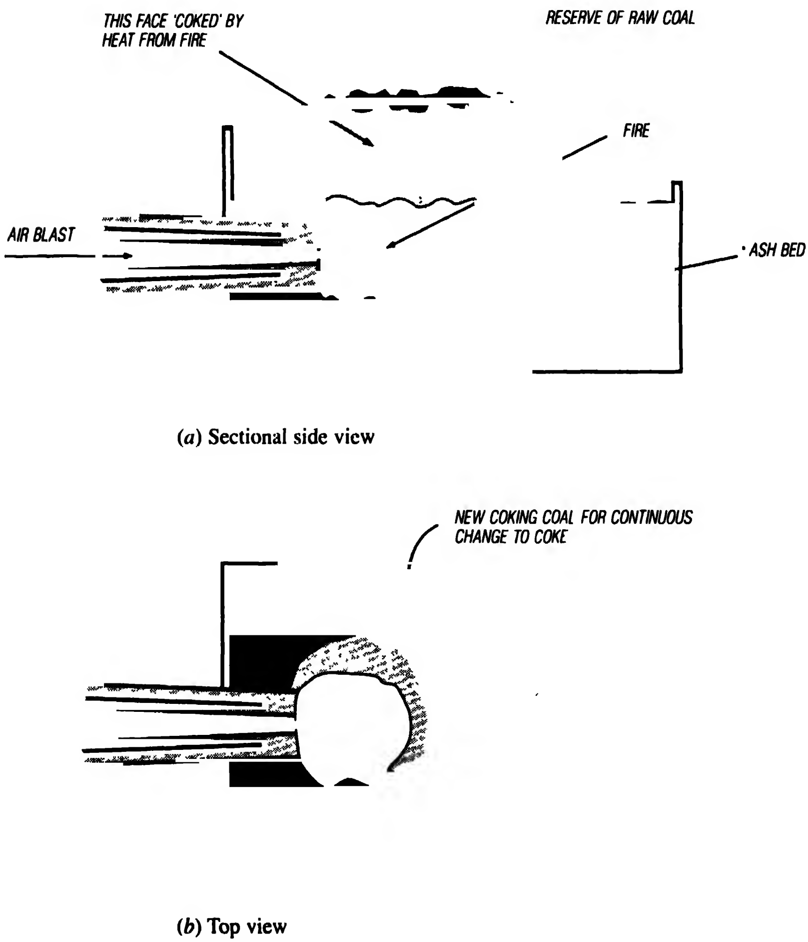


Fig. A18.7. Method of obtaining coke from bituminous coal in the forge.

City and Guilds of London Institute Examination questions

Note: All dimensions are given in millimetres, unless otherwise stated.

Manual metal arc

1 State *four* precautions which should be taken to protect the eyes and skin of the welder and other workers exposed to radiation from arc welding operations.

2 Sketch and label *three* defects that may occur in a double-vee butt welded joint which would affect fatigue strength.

3 Give *three* reasons why hydrogen-controlled electrodes are often used in preference to general purpose electrodes for welding low-alloy steels.

4 (*a*) Explain why the degree of penetration is greater using a cellulose-covered electrode compared to a rutile-covered electrode using the same heat input.

(*b*) An electrode used for manual metal-arc welding has over 100 per cent metal recovery. State

(1) the addition which must have been made to the covering,

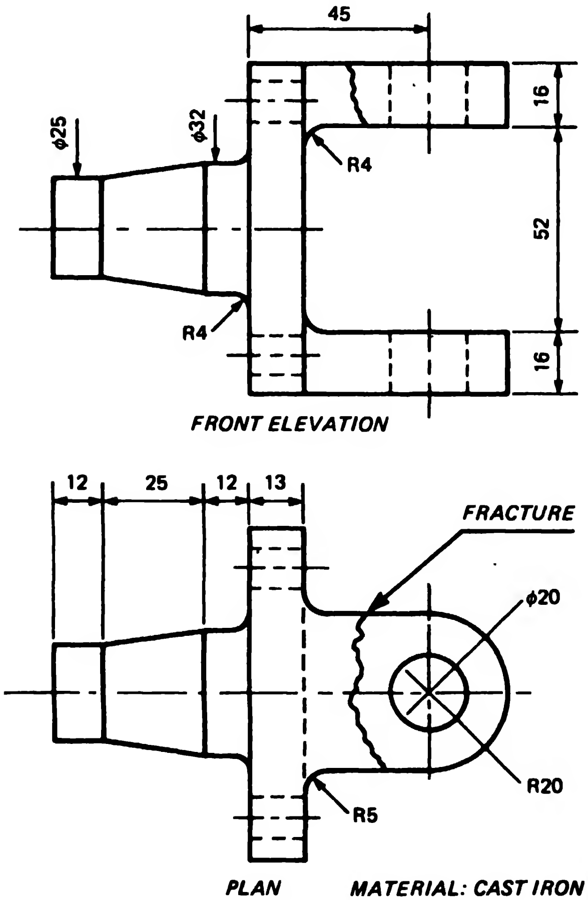
(2) *two* advantages of using this type of electrode.

5 The figure shows two views of a fractured grey cast-iron bracket which is to be repaired by the manual metal-arc process.
  (*a*) Make a pictorial sketch of the bracket.
  (*b*) List *eight* items of information that should be included on a welding procedure sheet for the repair of the bracket.
  (*c*) State *four* additional difficulties that would occur if the bracket has been made from 3% silicon alluminium alloy.

6 Give *three* reasons why hot cracking may be a problem when manual metal-arc welding austenitic stainless steel.

7 List *four* factors that should be considered when determining the pre-heating temperature to be used for welding a steel fabrication.

Question 5



8 (*a*) A 30 mm thick alloy of the composition shown has to be manual metal-arc welded using rutile-coated electrodes.

Composition: 0.2% carbon; 2% chromium; 0.5% molybdenum; 0.8% manganese; 0.4% silicon; 0.35% sulphur; 0.035% phosphorus; remainder iron.

$$\text{Carbon Equivalent} = \%C + \frac{\%Mn}{20} + \frac{\%Ni}{15} + \frac{\%Cr + \%Mo + \%V}{10}$$

(1) Using the formula given calculate the carbon equivalent of the alloy.

(2) From the information given in the table below construct a graph and from it determine the pre-heating temperature of the alloy.

Carbon equivalent %	0.3	0.35	0.4	0.45	0.5	0.55	0.6
Pre-heat temp. (°C)	100	150	200	250	300	350	400

(3) If a hydrogen-controlled electrode is used to weld the material explain why the pre-heating temperature may be lowered by 100°C.

(*b*) Two of the hazards which may arise in welding are explosions and fumes. For any *one* of these state *four* possible causes and the precautions that should be taken to avoid them.

9 Brittle fracture may occur in welded structures in low-alloy steels.

(1) List *four* possible causes.

(2) State *four* precautions that should be taken in order to reduce its occurrence.

(3) Describe one test procedure which may be used to give information on the parent plate's susceptibility to this type of failure.

10 (*a*) Explain what is meant by percentage metal recovery in manual metal-arc welding.

(*b*) Electrode manufacturers claim that over 100% metal recovery is possible when using certain of their electrodes.

(1) State the addition which must be made to the coatings of these electrodes.

(2) State *two* advantages.

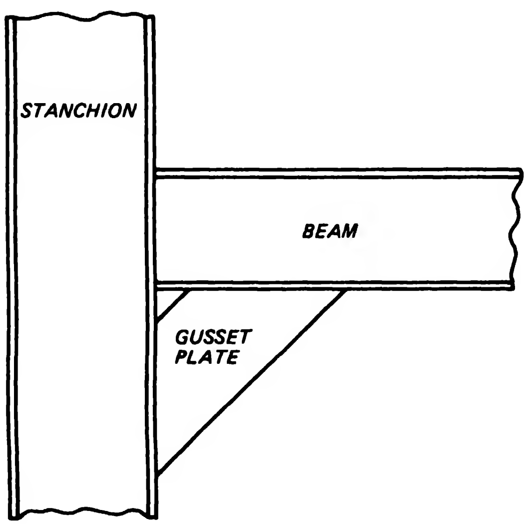
11 (*a*) State *two* factors that should be considered before selecting a filler electrode for a hard surfacing application.
(*b*) State *three* precautions which may be taken by the welder to control the level of dilution when surfacing using an arc welding process.

12 Steel components are to be hardfaced by the manual metal-arc process.
(*a*) Give *two* reasons why cracking may occur.
(*b*) State *three* precautions that can be taken in order to reduce the possibility of cracking.
(*c*) Name *one* other problem that may arise when hardfacing.

13 (*a*) With the aid of sketches, show *two* examples of distortion caused by manual metal-arc welding.
(*b*) For *each* example shown, suggest a suitable method of controlling the distortion.

14 The figure shows a typical beam-to-stanchion connection used in structural steelwork. Copy the drawing as shown and insert the appropriate welding symbols to indicate the following:
(*a*) the gusset to be fillet welded on each side to the stanchion in the shop;
(*b*) the beam to be added on site, and fillet welded all round to the stanchion;
(*c*) the gusset to be fillet welded each side to the beam.

Question 14



15 (*a*) Name two functions of the filter glasses used when metal-arc welding.
(*b*) Why should the cable used for the welding lead connexion of an arc welding circuit be flexible?
(*c*) Name two types of arc welding processes in which non-consumable electrodes are used.
(*d*) Give one example of a semi-automatic arc welding process.

16 Name *four* different types of metal-arc welding plant which fulfil the electric power supply requirements for welding. Describe, with aid of a sketch, one of the plants named.

17 What would be the practical effect of each of the following during metal arc welding:
(*a*) loose circuit connexions;
(*b*) variations in the mains supply voltage?

18 Describe in detail, with the aid of sectional sketches, three defects which may be produced during the metal-arc welding in the horizontal–vertical position of close-square-tee joints in mild steel plate. In *each* case state the cause and explain how the defects should be avoided.

19 Explain briefly the effect of any two of the following upon the production of an efficient joint in a partially chamfered butt weld:
(*a*) depth of root face,
(*b*) the angle of the vee,
(*c*) the gap setting.

20 Describe, with the aid of a sketch, one manual metal-arc welding technique used for making butt welds in mild steel pipelines.

21 Explain, by means of sketches, what is meant by *each* of the following:
(*a*) The *slope and tilt* of the filler rod and blowpipe *when making* a butt weld in low-carbon steel, 2 mm thick, in the vertical position by the oxy-acetylene process.
(*b*) The *slope and tilt* of the cutting electrode *when making* a straight cut in 8 mm low-carbon steel plate in the flat position by the oxygen-arc process.

22 (*a*) State *three* factors which may influence slag control during manual metal-arc welding.
(*b*) Give *one* example of when each of the following are used in manual metal-arc welding:
(1) tong test ammeter,
(2) voltmeter.

23 (*a*) What is meant by (1) open circuit voltage, and (2) arc voltage in manual metal arc welding?
(*b*) State the likely effect on root penetration and weld deposit when manual metal-arc welding low-carbon steel 6 mm thick with too long an arc.

24 State *two* safety precautions which should be observed with *each* of the following for manual metal-arc welding:
(*a*) treating components prior to welding by the use of trichloroethylene degreasing plant,
(*b*) welding in confined spaces,
(*c*) welding in close proximity to glossy finished surfaces,
(*d*) preparing vessels which have contained liquids with flammable vapours for repair by welding.

25 (*a*) Sketch the joint set-up and state the diameter of electrodes and current values to be used when making butt welds in the flat position in *each* of the following thicknesses of low-carbon steel:
(1) 3 mm,
(2) 6 mm,
(3) 10 mm.
(4) 14 mm,
(*b*) Discuss the effect of *each* of the following factors on depth of root penetration when making butt welded joints in the flat position:
(1) current,
(2) arc length,
(3) speed of travel,
(4) angle of electrode (slope and tilt).

26 State why pre-heating is to be recommended when welded joints are to be made in *each* of the following:
(*a*) low-alloy, high-tensile steel in cold weather,
(*b*) 50 mm thick low-carbon steel,
(*c*) 6 mm thick copper plate.

27 The figure shows two views of a cast iron support bracket which has fractured in service.
(*a*) If the casting is to be replaced by a low-carbon steel welded fabrication:
(1) make a sketch showing the complete bracket assembled ready for welding. By the use of weld symbols (BS499) indicate the type and location of the weld joints;

(2) detail freehand the steel parts that you would require.

(*b*) If the casting is to be repaired by manual metal arc welding state:

(1) all preparations necessary to be made before welding;

(2) the weld procedure, including details of electrode and current values;

(3) any precautions to be carried out after welding.

28 Explain briefly why nickel is liable to crack when metal-arc welded. State briefly how this defect may be avoided.

29 With the aid of sketches, give two examples of distortion of welded work that may result from the application of metal-arc welding.

30 (*a*) Explain what is meant by the term 'arc eye'.

(*b*) What precautions should be taken to avoid 'arc eye'?

(*c*) What action should be taken in the case of severe 'arc eye'?

31 When each of the following materials is welded by the manual metal-arc process state, in each case, two difficulties which may arise:

(1) copper, (2) grey cast iron.

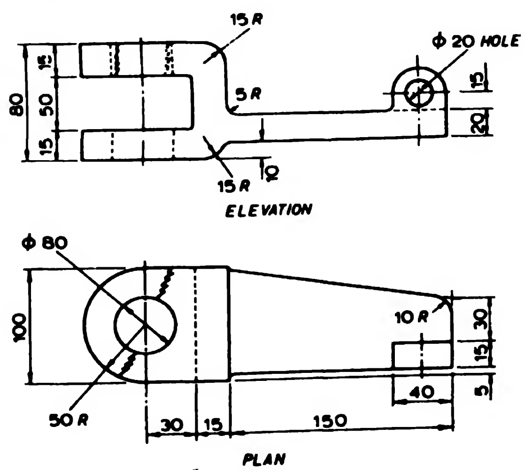
(*a*) State two difficulties which may be encountered when manual-metal arc welding dissimilar metals.

(*b*) Explain how these difficulties can be overcome.

32 Give *three* precautions which should be taken to produce acceptable joints when manual metal-arc welding austenitic stainless steel. Butt welds are to be made in the construction of a pipe line.

(*a*) Give *two* reasons why excessive penetration should be avoided.

Question 27



(*b*) Describe briefly *two* methods of controlling root penetration.

33 Describe, with the aid of sketches, any *four* of the following. In *each* case state *one* typical application, *one* advantage and *one* limitation:

(*a*) stove pipe technique,
(*b*) tongue bend test,
(*c*) manipulators,
(*d*) arc on gas techniques,
(*e*) 'studding' when welding cast iron.

34 Describe, with the aid of sketches, each of the following:

(*a*) back-step welding,
(*b*) backing strips,
(*c*) backing bars.

35 The figure shows details of a pipe assembly. Answer the following:

(*a*) Recommend a suitable method in each case for producing to correct shape and size (1) the flanges, (2) the main pipe and the branch pipe.
(*b*) Describe, with the aid of sketches, a suitable edge preparation that may be used to ensure satisfactory penetration at the following joints: (1) a flange to the main pipe, (2) branch pipe to the main pipe.
(*c*) Show, with the aid of sketches, the procedure for welding both of these joints, stating the sequence of runs, the current value and diameter of electrode used in each case.
(*d*) Describe briefly how the finished welds may be tested for surface defects.

36 The figure shows details of a pipe assembly. Answer the following:

(*a*) Show, by means of a sketch, how the main pipe and the flanges may have distorted as a result of welding.
(*b*) Sketch a simple fixture that would be suitable for locating the branch to the main pipe and assist in controlling distortion.
(*c*) Describe briefly a suitable method for pressure testing the completed assembly.
(*d*) Calculate the total weight of the three flanges; 1 m^3 of low-carbon steel weighs 7750 kg.

37 Briefly explain the function of *each* of the following in manual metal-arc welding:

(*a*) a low-voltage safety device,
(*b*) a rectifier.

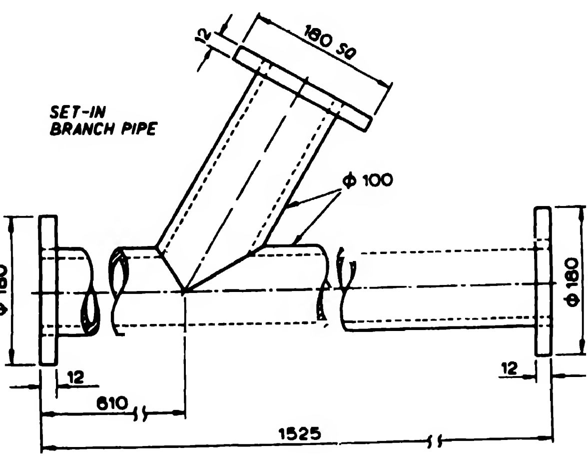
38 (*a*) What are the *three* basic types of wear to which hard-faced components are subjected?
(*b*) Select *one* of these types and suggest a suitable type of electrode to be used for surfacing to meet requirements.
(*c*) State *two* precautions which should be taken to minimize cracking.

39 An aluminium alloy casting is to be repaired by the manual metal-arc welding process. Give *each* of the following:
(*a*) a workshop method of indicating the pre-heating temperature,
(*b*) the type of current to be used.
(*c*) *three* factors which make this material more difficult to weld than low-carbon steel.

40 Select a suitable electrode for welding *each* of the following low-carbon steel joints:
(*a*) a severely stressed single-vee butt joint welded in the flat position,
(*b*) a lightly stressed fillet welded joint in the vertical position,
(*c*) fillet welds in the flat position where a high metal recovery rate is required.

41 State one important safety precaution that must be observed for each of the following:
(*a*) before commencing welding repair work on a two-compartment tractor fuel tank, having one compartment used for petrol and the other for fuel oil;

Question 35 and 36



(*b*) when flame gouging in the vertical position a defective vertical joint out of a heavy fabrication in preparation for rewelding.

42 State *two* advantages which may be obtained by the use of a U preparation instead of a V preparation for welded butt joints in thicker materials.

43 Sketch the joint preparation and set-up, and state the size of the electrodes, number of runs and current values to be used for making

(1) butt welds, without backing bar in the flat position,

(2) tee fillet welds in the horizontal–vertical position, in each of the following thicknesses of mild steel: 6.4 mm and 12.7 mm.

44 State the plate thickness limitations of the upward–vertical and the downward–vertical metal arc welding techniques.

45 (*a*) Describe, with the aid of sketches, what effect each of the following would have on the depth of root penetration and the quality of the deposited metal:

(1) the use of too high current value,

(2) incorrect angle of electrode slope,

(3) too fast a speed of travel,

(4) incorrect arc length.

(*b*) Explain how measuring equipment could be used to check current and voltage values available in a metal arc welding circuit during welding.

46 State one safety precaution that must be carried out:

(*a*) before commencing welding repair work on a tank which has contained acids,

(*b*) when metal arc welding from a multi-operator set is carried out during the construction of multiple-storey steel framed structures.

47 State what is meant by:

(*a*) deep-penetration coated electrode,

(*b*) non-consumable electrode.

48 What is the purpose of a choke reactance used in manual metal arc welding?

49 (*a*) What is meant by arc blow in manual metal arc welding?

(*b*) Arc blow may arise when manual metal arc welding with either direct current or alternating current supply. Give *two* possible causes.

50 (*a*) State what is meant by:

(1) rutile-coated electrode,

(2) hydrogen-controlled coated electrode.

(*b*) Give *one* defect which may arise when manual metal arc welding low-carbon steel, using an eccentrically coated electrode.

51 Describe with the aid of sketches the *technique* required when cutting low-carbon steel plate in the flat position by the use of *each* of the following arc cutting processes:
(1) air-arc,
(2) oxygen-arc.

52 Sketch and label *two* different types of edge preparation for butt joints other than close-square butt, suitable for manual metal arc welding.

53 Give *one* possible cause of *each* of the following defects when manual metal arc welding close-square-tee fillet joints in low-carbon steel in the vertical position by the upwards technique:
(*a*) incomplete root penetration,
(*b*) undercut,
(*c*) unequal leg-length.

54 (*a*) Explain what is meant by 'percentage metal recovery' in metal arc welding.
(*b*) If over 100% is claimed, what additions could have been made to the electrode coating?

55 Manufacturers of metal arc welding electrodes take care to specify a minimum and maximum current for each size and type of mild steel electrode. Discuss in detail the important consequences of using
(*a*) insufficient current,
(*b*) excessive current.

56 (*a*) State *three* reasons for using welding fixtures in welding fabrication.
(*b*) State *three* basic factors that must be considered for the effective operation of a welding fixture.
(*c*) Describe briefly, with the aid of a sketch, the principle of operation of any welding fixture with which you are acquainted.

57 A number of butt welded joints have to be made between the ends of 100 mm diameter low-carbon steel pipe. Sketch a simple jig for holding them in position for tack welding.

58 Give *four* important functions of a slag.
(*a*) Briefly describe one test, other than visual inspection, used to reveal surface defect in welded joints.
(*b*) Give one limitation of such a test.
(*c*) Name four constituents used in electrode coatings.

(*d*) State the most important function of any one of these constituents.

59 Give *four* differences in the behaviour of the metal that a welder will find between the metal arc welding of (*a*) aluminium and (*b*) low-carbon steel.

60 (*a*) Describe in detail the metal arc welding process commonly used for manually welding mild steel.
(*b*) Give *two* examples showing how the process in (*a*), using standard electrodes, may be partially automated so as to reduce costs.

61 State *three* factors that may influence metal transfer phenomena when using a metal arc welding process.

62 Give *three* reasons why stray-arcing is undesirable.

63 Give *three* reasons why damp flux-coated electrodes should not be used for welding mild steel.

64 With the aid of a sketch, show the principle of the buttering technique.

65 (*a*) Construct a table showing the ranges of welding currents typically used with 2.5 mm, 3.2 mm, 5.0 mm and 6.0 mm general-purpose, mild steel electrodes.
(*b*) Plot a graph from the figures in the table in part (*a*).
(*c*) From the graph in part (*b*) determine the probable current range to be used with a 4.0 mm electrode.

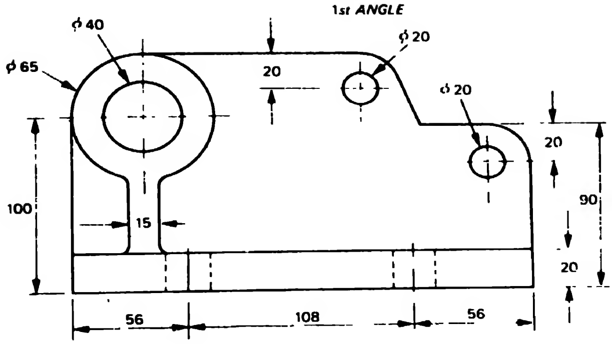
66 State *three* safety precautions to be observed when using engine-driven metal arc welding equipment.

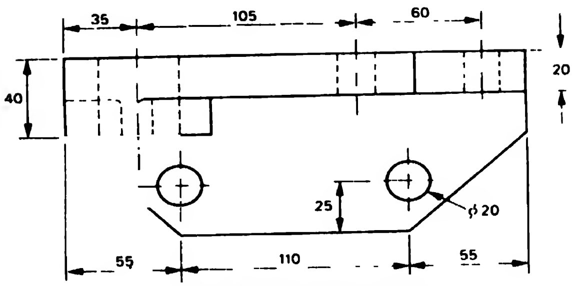
67 Give any *two* advantages of using multi-operator a.c. metal arc welding equipment.

68 The figure shows two views of a bracket which has to be fabricated by manual metal arc welding.
(*a*) Make a pictorial sketch of the bracket and indicate, by the use of weld symbols, according to BS499, the location and the type of weld joints required.
(*b*) List *ten* items of information that could be included on a Welding Procedure Sheet for the bracket shown.

69 The figure shows two views of a cast iron bracket which has fractured in service.
(*a*) If the casting is to be repaired by manual metal arc welding,
(1) state *all* preparations necessary to be made before welding,
(2) describe a suitable procedure, including details of the type of electrodes and the current values,
(3) state *two* precautions carried out after welding.

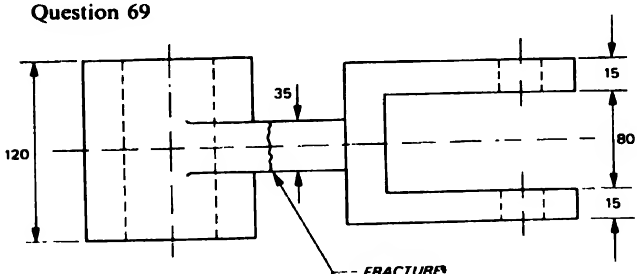
Question 68

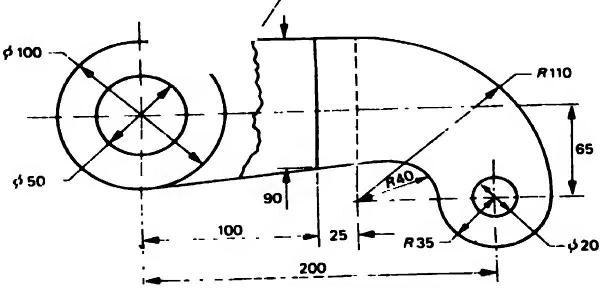




ALL DIMENSIONS IN MILLIMETRES

Question 69





ALL DIMENSIONS IN MILLIMETRES

(*b*) Make a sketch to show the complete bracket assembled ready for welding, if the casting is to be replaced by a low-carbon steel welded fabrication. By the use of weld symbols (BS499), indicate the type and location of the weld joints to be used.

70 Give *one* reason why, in particular situations, it might be difficult to control the arc when arc welding mild steel.

71 Give what you consider to be *three* important factors likely to affect the cost of the welded fabrication of a very large one-off component.

72 (*a*) By means of a labelled sketch show what is meant by buttering.

(*b*) Name *one* material on which buttering could helpfully be used to make an effective arc fusion welded joint.

73 Explain how the difficulties which may arise from the presence of hydrogen may be overcome during the welding of low-alloy steels.

74 What is an alloy? Give *two* reasons why an alloying addition might be necessary in the composition of a metal intended for use as weld metal for joints to be made by gas-shielded arc welding.

Gas shielded metal arc MIG *and* TIG

1 (*a*) List *four* welding problems to be overcome when gas-shielded metal-arc welding austenitic heat-resisting steels to be used for high-temperature service.

(*b*) State *three* features which should be present in a manipulator intended for extensive gas-shielded metal-arc welding of joints in a large assembly.

(*c*) Outline *three* functions of jigs designed to be used for the metal-arc gas-shielded welding of joints in components during flow production.

2 (*a*) State *five* factors which influence the cost of metal-arc gas-shielded welding in the batch production of welded fabrications in non-ferrous metals.

(*b*) A butt welded joint in a flat, low-carbon steel bar L mm wide and t mm thick is to be made by the metal-arc gas-shielded process. When in service a static tensile load of P newtons will be carried by the butt welded joint. Show by means of a simple formula how the tensile stress in the butt weld may be calculated.

(*c*) Describe, with the aid of sketches, a technique which may be used for making a fillet welded part-lapped close outside

corner joint in the flat position in 6 mm thick aluminium plate by the metal-arc gas-shielded process.

3 (*a*) With the aid of a labelled block diagram to show the arrangement, describe the equipment necessary to fulfil the electrical gas-shielding and ancillary requirements when one operator is required to carry out effective tungsten-arc gas-shielded welding with
   (1) alternating current,
   (2) direct current as required for different types of material.

(*b*) State the purpose of *each* item of equipment in the system and give details of current control together with a labelled sketch to show the power source characteristic.

4 (*a*) State *four* different-types of material suitable for tungsten-arc gas-shielded welding.

(*b*) In the case of *two* of these materials state
   (1) *two* difficulties that may arise during the welding of the material,
   (2) the methods used to overcome the difficulties encountered.

5 (*a*) List *four* gases *or* gas mixtures used in tungsten-arc welding and give *one* typical application of *each*.

(*b*) Describe with the aid of sketches, a technique used for making a close-square butt joint in the vertical position by the upward method in 2.5 mm thick austenitic stainless steel by the tungsten-arc process.

(*c*) State *four* possible causes of incomplete penetration when making butt welds by the tungsten-arc process in the flat position.

6 (*a*) Outline *two* essential functions of the gas shield required for effective gas-shielded metal-arc welding.

(*b*) List *four* gases *or* gas mixtures, other than carbon dioxide, used in metal-arc gas-shielded welding and give *one* typical application of *each*.

(*c*) State *two* possible causes of *each* of the following defects when encountered in welds made by the metal-arc gas-shielded process in low alloy steel:
   (1) porosity,
   (2) cracking.

(*d*) Explain why care should be taken to avoid leakage at joints in the shielding gas supply lines when gas-shielded metal-arc welding aluminium alloys.

7 (*a*) Show, by means of a labelled diagram, the voltage waveform obtained when using *either* a high-frequency unit *or* a surge injector for gas-shielded tungsten-arc welding with alternating current supply.
(*b*) State the function of each of the regularly alternating high and low current levels used in controlled spray (pulse) mode of metal transfer in gas-shielded metal-arc welding.

8 (*a*) Outline *one* method of arc length control which may be used in metal-arc gas-shielded welding.
(*b*) Show, by means of labelled sketches, the stages in spray mode of metal transfer when metal-arc gas-shielded welding.

9 (*a*) Explain, with the aid of a sketch, how the level of dilution of a butt-welded joint may be determined.
(*b*) Show by means of a labelled sketch *one* type of edge preparation used to control pick-up effects when making a butt-welded joint in clad steel.

10 The following gas shielding mixtures are used in gas-shielded arc welding:
(*a*) argon,
(*b*) argon and hydrogen,
(*c*) argon and oxygen,
(*d*) argon and nitrogen,
(*e*) argon and helium.
State, in *each case*, a material and the welding process for which these mixtures are best suited.

11 (*a*) Name the type of current and electrode required for gas-shielded tungsten-arc welding *each* of the following materials:
(1) low-carbon steel,
(2) aluminium alloy,
(3) copper alloy.
(4) austenitic stainless steel.
(*b*) State *two* factors, other than thickness of material, which should be considered when selecting the filler wire diameter to be used for tungsten-arc welding.

12 (*a*) Outline the procedure for rectifying a fault which has been indicated in a metal-arc gas-shielded welding circuit by failure to strike an arc and a falling voltage reading at the power source.
(*b*) Show, by means of a sectional sketch, the contact tube

setting and electrode extension required for dip transfer welding of low-carbon steel.

13 (*a*) Sketch a tungsten-arc welding torch fitted with a gas lens and increased electrode extension, indicating the pattern of gas flow which would be obtained from the torch.

(*b*) State *two* reasons why rectification must be controlled when alternating current is used for the gas-shielded tungsten-arc welding of aluminium.

14 (*a*) State *two* safety precautions, other than ventilation, which are necessary when using gas-shielded arc welding processes.

(*b*) State how

(1) ozone,

(2) carbon monoxide

may be formed during gas-shielded arc welding.

15 (*a*) State the purpose of a choke reactance when used for gas-shielded metal-arc welding.

(*b*) State the function of

(1) a surge injector,

(2) a high frequency unit,

when tungsten arc welding with alternating current.

16 Show by means of a labelled diagram of output curves the essential differences between the characteristics of the power source suitable for

(*a*) manual tungsten-arc gas-shielded welding,

(*b*) semi-automatic metal-arc gas-shielded welding with a self-adjusting arc.

17 (*a*) State what current values are being shown by the ammeter when welding with controlled spray (pulse) mode of metal transfer.

(*b*) Show, by means of labelled sketches, the stages in metal transfer when metal-arc gas-shielded welding by means of dip mode of metal transfer.

18 State, in *each* case, *two* precautions which must be taken in the storage of

(*a*) electrode wires for metal-arc gas-shielded welding,

(*b*) filler wires for tungsten-arc gas-shielded welding,

to ensure effective welding when required.

19 (*a*) During gas-shielded tungsten-arc welding, porosity has appeared in the weld face and metal deposition has become difficult. State *two* possible causes that may produce this condition.

(*b*) Give *one* suitable material in *each* case which may be used for a backing bar insert when tungsten-arc gas-shielded welding
(1) ferrous metals,
(2) non-ferrous metals.

20 (*a*) Give *two* undesirable effects which may occur when using excessive wire feed speed during gas-shielded metal-arc welding.
(*b*) State the shielding gas or gas mixture which is best suited to obtain the required modes of metal transfer for the efficient metal-arc gas-shielded welding of *each* of the following metals:
(1) low-carbon steel and low-alloy steel by spray transfer in the flat position,
(2) austenitic stainless steel and aluminium by controlled spray (pulse) transfer in the vertical position.

21 (*a*) State how gas flow rate is controlled and measured to enable the production of efficient welded joints in tungsten-arc gas-shielded welding.
(*b*) Name *four* factors upon which the selection of the correct current value will depend in tungsten-arc welding.

22 (*a*) Give *two* advantages which may be obtained by the use of the metal-arc gas-shielded spot welding process instead of the electric resistance spot welding process.
(*b*) State *one* typical application in each case for the following welding process:
(1) electron beam,
(2) friction.

23 (*a*) Outline the procedure for rectifying a fault which has been indicated in a metal-arc gas-shielded welding circuit by failure to strike an arc and a falling voltage reading at the power source.
(*b*) Show, by means of a sectional sketch, the contact tube setting and electrode extension required for dip transfer welding of low-carbon steel.

24 (*a*) Sketch a tungsten-arc welding torch fitted with a gas lens and increased electrode extension, indicating the pattern of gas flow which would be obtained from the torch.
(*b*) State *two* reasons why rectification must be controlled when alternating current is used for the gas-shielded tungsten-arc welding of aluminium.

25 Explain why the presence of moisture should be avoided when gas-shielded arc welding low-alloy steels.

26 (*a*) State in *each* case *one* probable cause of the following weld defects in joints made by tungsten-arc welding:
(1) lack of root penetration,
(2) porosity.
(*b*) State *two* reasons why abrupt changes of section should be avoided in the contours of a welded joint.

27 (*a*) Outline *two* essential functions of the gas shield required for tungsten-arc welding.
(*b*) State *two* factors which influence the selection of the flow rate of argon gas necessary to obtain efficient welded joints.
(*c*) State in *each* case *two* difficulties that may arise during the tungsten-arc welding of
(1) stainless steel,
(2) aluminium,
(3) magnesium alloy.

28 (*a*) Describe, with the aid of a sketch, the distortion effects which are likely to be produced when an unrestrained 450 mm long single-vee butt joint between 6 mm thick austenitic stainless steel plates 225 mm wide is made by the tungsten-arc process in two runs from one side.
(*b*) Give *two* methods used to control distortion.
(*c*) Outline, with the aid of sketches, *two* methods of providing gas backing for the butt welding of pipe joints.

29 (*a*) Outline the shut-down procedure to be followed at the end of work with tungsten-arc welding plant in order to ensure safety and continued efficiency of equipment.
(*b*) Show, by means of a labelled sketch, the gas paths and the function of *each* of the main components of a water-cooled tungsten-arc welding torch.
(*c*) Describe, with the aid of sketches, a tungsten-arc technique used for making a close-square butt-welded joint in the vertical position by the upward method in 1.5 mm thick austenitic stainless steel.

30 (*a*) Describe, with the aid of a labelled block arrangement diagram, the purpose of each part of the equipment essential for argon-shielded metal-arc welding aluminium alloys.
(*b*) State *one* precaution which must be taken with the temporary backing bars used in welding aluminium alloys in order to ensure the production of efficient joints.

(*c*) State the shielding gas or gas mixture which is most suited to obtain controlled spray (pulse) mode of metal transfer for welding
(1) low alloy steel,
(2) aluminium.

31 (*a*) List *four* welding problems to be overcome when welding steel containing 9% nickel, which is to be used for low-temperature service.
(*b*) State *three* features which should be present in a jig designed for use in the welding of joints made in components during batch production.
(*c*) Describe, with the aid of sketches, a gas-shielded metal-arc technique which may be used for making a lap-fillet welded joint in the vertical position by the downward method in 3 mm thick low-carbon steel plate.

32 (*a*) List *three* advantages and *three* disadvantages in *each* case which may be obtained by the use of
(1) carbon dioxide,
(2) argon,
for metal-arc gas-shielded welding.
(*b*) Outline *two* effects of the chromium content on the weldability of low-alloy high-tensile steel.
(*c*) State *two* essential factors which must be considered before making welded joints between dissimilar metals by the metal-arc gas-shielded welding process.

33 (*a*) Give *two* reasons why it is necessary to be particularly careful with the insulation of components in the welding circuit when using high-frequency current in tungsten-arc gas-shielded welding operations.
(*b*) Give *two* safety precautions which should be taken when preparing to use the metal-arc gas-shielded welding process for making welds on site in an exposed position which is 12 metres above ground level.

34 (*a*) State the purpose of a drooping voltage transformer-rectifier when used for tungsten-arc gas-shielded welding.
(*b*) Outline *two* methods used to control the current surges at the short-circuitings which take place when metal-arc gas-shielded welding with dip mode of metal transfer.

35 (*a*) Explain what is meant by *each* of the following in fusion welding:
(1) dilution,
(2) pick-up.

(*b*) Show by means of a labelled sketch *one* type of joint preparation used to control pick-up effects when making a butt-welded joint in clad steel.

36 (*a*) State *two* reasons why the d.c. component must be suppressed when alternating current is used for gas-shielded tungsten-arc welding.

(*b*) Outline, with the aid of a sketch, *one* method of providing back purging for the butt welding of a joint in flat plate by the tungsten-arc process.

37 (*a*) State *one* undesirable effect in *each* case which is likely to be produced when metal-arc gas-shielded welding with wire feed drive roll pressure adjustment which is

(1) insufficient,

(2) excessive.

(*b*) Give *four* routine checks which should be made on the electrode wire before fitting a new spool into a gas-shielded metal-arc welding plant.

38 Distortion may result from gas-shielded arc welding operations. State *two* possible causes and give *two* methods of control.

39 (*a*) Give *one* reason in *each* case for the use of

(1) a remote control switch,

(2) a welding contactor,

in tungsten-arc welding.

(*b*) State the likely effect of allowing cables in the welding circuit to coil when using high-frequency currents in gas-shielded tungsten-arc welding.

40 (*a*) Explain the technique to be followed to avoid contamination of the electrode when tungsten-arc welding butt joints in thicker section material in the flat position.

(*b*) Give *two* advantages which may be obtained by the use of the two-operator upward-vertical technique for tungsten-arc welding.

41 (*a*) Give *two* reasons why flux-cored electrode wire is used with carbon dioxide shielding for the metal-arc gas-shielded welding of steel.

(*b*) When using a gas-shielded arc welding process, on an exposed site, which *two* problems are most likely to be encountered as a result of weather conditions?

42 (*a*) What advantageous feature is provided by a constant potential power source when the arc is initiated to start the weld in metal-arc gas-shielded welding?

(*b*) Outline the procedure for rectification when a fault con-

dition has been indicated in a metal-arc gas-shielded welding circuit, by falling voltage reading at the power source, when the end of the electrode wire is touched on to the work with the torch control trigger actuated.

43 Name *four* factors which may affect the cost of metal-arc gas-shielded welding a fabrication in a non-ferrous alloy.

44 With the aid of a sketch, explain briefly the principles of the tungsten-arc spot welding process.

45 (*a*) Describe, with the aid of a sketch, the distortion effects which are likely to be produced when an unrestrained 300 mm long single-vee butt joint between 5 mm thick austenitic stainless steel plates, 150 mm wide, is made in two runs from one side by the tungsten arc process.

(*b*) Outline *two* methods used to control distortion in tungsten-arc welding operations.

46 List *four* of the main welding problems encountered when tungsten-arc gas-shielded welding magnesium alloys in thicknesses ranging from 2 mm to 10 mm, indicating how *each* of these problems is overcome, and mentioning the effects of surface preparation.

47 Twenty 2 metre pipe lengths are to be fabricated from existing stock of 1 metre lengths of 150 mm internal diameter low-carbon steel pipe of 10 mm wall thickness by metal-arc gas-shielded welding. Describe, with the aid of sketches, *each* of the following for the welding of one joint:

(*a*) a suitable joint preparation and set-up,
(*b*) the assembly and tack welding procedure,
(*c*) the mode of metal transfer, shielding gas and electrode wire size to be used,
(*d*) an effective welding procedure.

48 (*a*) Compare the use of carbon dioxide with the use of argon for metal-arc gas-shielded welding by listing *two* relative advantages and *two* relative disadvantages which may be obtained by the use of *each* gas.

(*b*) State *two* advantages which may be obtained by the use of a manipulator as an aid to fabrication by metal-arc gas-shielded welding.

49 State the sequence which could be used to complete the joints numbered 1, 2, 3, and 4 in the figure of a welded fabrication made from five parts as shown. Give reasons for your answer.

50 For joint 1 in the figure give details of (*a*) the type of preparation and (*b*) the welding procedure to be used.

51 For joint 2 in the figure give details of (*a*) the type of preparation and (*b*) the welding procedure to be used.

52 Describe briefly four problems which may be encountered in the welding of the fabrication shown in the figure.

53 State why a self-adjusting arc is 'not likely to operate effectively in CO_2 shielded metal-arc welding'.

54 By means of a labelled block diagram show clearly the equipment required to give effective control of gas flow to the torch or welding head during gas-shielded arc welding. Assume that a suitable gas is being used.

55 By means of a labelled sketch indicate any *three* types of weld defect likely to occur in gas-shielded arc welded joints.

56 What is the purpose of a suppressor unit in a gas-shielded arc welding circuit?

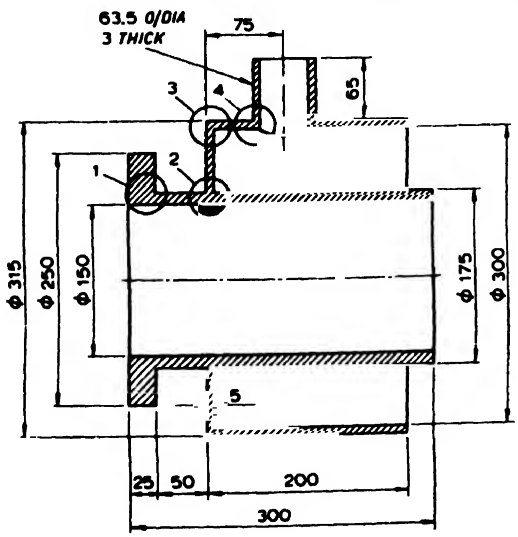
57 State *three* different types of material suitable for tungsten arc gas-shielded welding. In *each* case state

   (*a*) two difficulties that may arise during the welding of the material,

   (*b*) the methods used to overcome the difficulties encountered.

58 With the aid of a simple labelled block diagram show the name, location and purpose of each part of the equipment essential for the effective tungsten-arc gas welding of aluminium.

Questions 49–52. Section through a heater shield. Material: 18% Cr, 8% Ni austenitic steel, Ti stabilized. Process: gas-shielded tungsten arc welding.



59 (*a*) Sketch a tungsten-arc welding torch fitted with gas lens, indicating the pattern of gas flow which would be obtained from the torch.
(*b*) State *two* advantages which may be obtained by the use of a gas lens in tungsten-arc welding.

60 (*a*) Describe briefly the recommended procedure to follow for clearing a 'burn back' in gas-shielded metal-arc welding.
(*b*) State *four* causes, other than joint preparation, of lack of root penetration in butt-welded joints made by gas-shielded metal-arc welding.

61 (*a*) Outline the typical main functions of a jig or fixture suitable for use in tungsten-arc gas-shielded welding.
(*b*) Give *two* situations in which the use of a jig or fixture would be considered essential, in the manufacture of a component by tungsten arc gas-shielded welding.

62 Explain what is meant by gas-backing in tungsten-arc welding and show *two* ways in which it may be applied.

63 List *two* advantages and *two* limitations of gas-shielded metal-arc welding as a process for general-purpose welding repair work.

64 With the aid of a simple labelled block diagram show the name, location and purpose of each part of the equipment essential for the effective CO_2 shielded metal-arc welding of low-carbon steels.

65 State *four* features which should be present in a manipulator intended for extensive gas-shielded metal-arc welding of joints in a large component.

66 (*a*) State the type of filter which should be used to provide eye and skin protection against radiation effects when gas-shielded arc welding with:
(1) the tungsten arc process,
(2) the metal arc process.
(*b*) Give *one* reason, in *each* case, for the type of filter used.

67 (*a*) What is the purpose of a choke reactance when used for gas-shielded metal-arc welding?
(*b*) State *two* effects which may be produced by using excessive electrode wire extension during welding.

68 (*a*) Give *two* advantages of tungsten-alloyed electrodes over plain tungsten electrodes when used for tungsten-arc welding.
(*b*) Show by means of simple labelled sketches what is meant by the electrode tip (vertex) angle when tungsten-arc welding with:
(1) alternating current,
(2) direct current.

69 Show by means of a single labelled sketch the essential differences between welding power source characteristics suitable for:
- (*a*) manual tungsten-arc welding,
- (*b*) welding with a self-adjusting arc.

70 (*a*) State *two* factors which influence the amount of dilution of the weld deposit in gas-shielded arc welding.
- (*b*) With the aid of an outline sketch, show how the level of dilution of the welded joint may be determined.

71 (*a*) State *two* modes of metal transfer, other than spray, used for gas-shielded metal-arc welding.
- (*b*) Give *one* application of *each* mode of transfer named.

72 (*a*) Give *two* important physical properties of ceramic gas nozzles.
- (*b*) State *two* of the factors which govern the gas-shielding necessary to obtain efficient welded joints by tungsten-arc welding.

73 (*a*) State the type of current and tungsten alloyed electrode recommended to be used for tungsten-arc welding *each* of the following materials:
  - (1) low-carbon steel up to 2 mm thick,
  - (2) austenitic stainless steel up to 5 mm thick,
  - (3) aluminium over 3 mm thick,
  - (4) magnesium alloy up to 5 mm thick.
- (*b*) List *three* gases or gas mixtures in tungsten-arc welding and give one typical use of each.

74 (*a*) State *four* factors that have to be taken into account when costing for tungsten-arc gas-shielded welding.
- (*b*) Explain what is meant by:
  - (1) arcing time,
  - (2) floor to floor time.

75 (*a*) List the main welding problems when tungsten-arc gas-shielded welding copper plates in thicknesses ranging from 3 to 10 mm.
- (*b*) Outline with the aid of sketches how each of these problems may be counteracted.

76 (*a*) Show by means of a labelled sketch *one* method of providing gas backing for the tungsten-arc welding of butt joints in plate in the flat position.
- (*b*) Why should syphon-type cylinders be used to supply carbon dioxide for shielding gas in welding?

77 With the aid of simple sketches show how you would prepare the joints for welding the top central part of the beam shown in the

figure, where the central boss and the top flange join with each other and where the vertical web joins with the top plate.

78 State the welding sequence which should be used for welding the beam shown in the figure. Give reasons for each step.

79 Describe four of the problems which are likely to arise in welding the ends of the beam shown in the figure.

80 On a sketch of the figure give all the information needed to show the type and location of each welded joint, using the system given in BS 499 (Part 2).

81 Give *three* reasons why a suitable shade of filter glass should be used for viewing the arc during gas-shielded arc welding.

82 The following gas-shielding mixtures are used in gas-shielded arc welding:

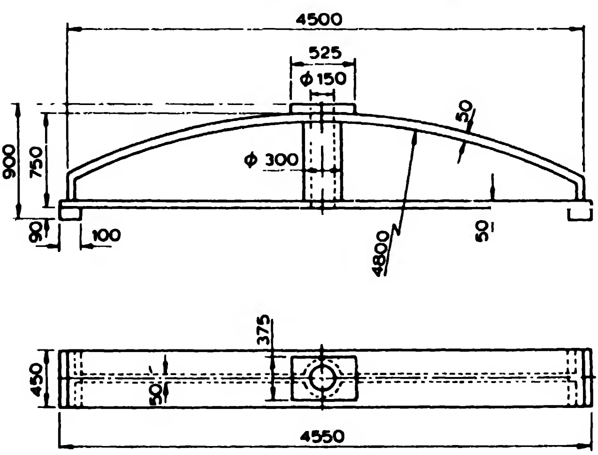
(*a*) argon + carbon dioxide + oxygen,
(*b*) argon + oxygen,
(*c*) argon + hydrogen,
(*d*) helium + argon,
(*e*) helium + argon + carbon dioxide.

State in *each* case:

(1) the material for which the mixture is best suited,
(2) the approximate percentages of gases in the mixture.

83 State *five* desirable features in jigs intended for gas-shielded metal-arc welding of joints in components to be mass produced.

Questions 77–80. Support beam. Material: high yield stress structural steel (BS 4360 Grade 50) welded by CO_2 shielded metal arc process.



84 (*a*) With the aid of a labelled block diagram to show the arrangement, describe the purpose of *each* part of the equipment necessary for the effective argon-shielded metal-arc welding of aluminium alloys.

(*b*) State *one* precaution which must be taken in *each* case, with:

(1) the shielding gas supply lines,

(2) temporary backing bars,

in order to assist in the production of efficient joints.

85 (*a*) Give *one* safety precaution to be taken before tungsten-arc gas-shielded welding when the gas cylinder is located near the welding area.

(*b*) Give *two* hazards present when metal arc gas-shielded welding equipment is inadequately earthed.

86 (*a*) State the purpose of a combined transformer-rectifier when used for tungsten-arc welding.

(*b*) Give *two* important reasons for the use of a welding contactor in tungsten-arc welding.

87 (*a*) State the type of current and tungsten alloyed electrode recommended to be used for tungsten-arc welding *each* of the following materials:

(1) low-carbon steel up to 2 mm thick,

(2) austenitic stainless steel up to 5 mm thick,

(3) aluminium over 3 mm thick,

(4) magnesium alloy up to 5 mm thick.

(*b*) List *three* gases or gas mixtures in tungsten-arc welding and give one typical use of each.

88 (*a*) State the purpose of a surge injector unit as used in arc welding.

(*b*) State the purpose of a suppressor unit as used in arc welding.

89 A cylindrical vessel 620 mm diameter by 2.5 metres long with low-carbon steel flanged ends 25 mm thick is to have two austenitic stainless steel pipes coming out at right angles to the vessel axis and to each other midway along the vessel axis. The pipes are 100 mm inside diameter with a wall thickness of 9.5 mm and the vessel is made of 12.5 mm thick low-carbon steel, clad inside with austenitic steel to a further 1.6 mm thickness. The pipes and flanges are to be joined to the vessel by gas-shielded tungsten-arc welding.

(*a*) Give particulars of (1) the type of joint, (2) the joint preparation and (3) the welding procedure that you recommend for the welding of flanges to the vessel.

(*b*) Give particulars of (1) the type of joint, (2) the joint preparation and (3) the welding procedure that you recommend for welding the pipes into the vessel.

90 A special I-section girder 6 metres long has the following sectional dimensions: flanges 450 mm wide by 50 mm thick, web 19 mm thick, and overall depth 1 metre. Stiffening ribs 150 mm wide by 12.5 mm thick, running from flange to flange, are located opposite each other against the web at right angles to the rider axis at 1.2 m intervals. The girder is to be fabricated from high-tensile constructional steel of welding quality by gas-shielded metal-arc welding.

(*a*) Give particulars of (1) the type of joint, (2) the joint preparation, and (3) the welding procedure that you would use for joining the web to the flanges.

(*b*) Give particulars of (1) the type of joint, (2) the joint preparation, and (3) the welding procedure that you would use for attaching the stiffening ribs.

91 There are particular economic and metallurgical problems associated with the effective use of gas-shielded metal-arc welding in production applications. Outline these problems and explain how they may be overcome.

92 Austenitic heat-resisting steels containing higher nickel and chromium contents are used for fabricating structures for high-temperature service.

(*a*) State *five* main welding problems that are likely to arise in the metal-arc gas-shielded welding of this type of material.

(*b*) Explain how *each* of these problems may be effectively overcome to ensure efficient welded joints for service at high temperatures.

93 (*a*) When a d.c. arc is operating, what proportion of the heat may be generated at each side of the arc?

(*b*) Would the heating situation be the same when tungsten-arc gas-shielded welding aluminium with the electrode positive?

94 A gas pressure regulator and a flowmeter are each essential for the successful operation of a gas-shielded arc welding process.

(*a*) With the aid of an outline diagram show the usual location of each in a conventional gas-shielded tungsten-arc welding arrangement.

(*b*) Why is it necessary to have a gas pressure regulator?

95 In gas-shielded tungsten-arc welding each of the following plays an important part: (1) length of electrode projecting beyond the nozzle, (2) length of arc, (3) angle of electrode relative to the workpiece.

Give *two* important reasons why small diameter filler wire is used for gas-shielded metal-arc welding.

96 (*a*) State one difficulty with the dip-transfer mode of metal deposition as it is used in CO_2 shielded metal-arc welding.
(*b*) State briefly how this difficulty is overcome.

97 On a simple labelled block diagram show the name and purpose of each essential part of the plant and equipment needed for making tungsten-arc gas-shielded welds in a variety of metals and a range of thicknesses.

98 Give two checks you should make on the electrode wire before fitting a new spool into a gas-shielded metal-arc welding machine.

99 Why is a double-bevel or a double J butt-welded tee joint preferable to a double fillet welded close-square-tee joint for welding two highly stressed members?

100 (*a*) Explain why, in spite of the overall efficiency of argon as a shielding gas, so much effort is spent in developing the use of gases such as carbon dioxide.
(*b*) Name two difficulties likely to be encountered in using carbon dioxide as a shielding gas in arc welding.
(*c*) For each of the difficulties given in your answer to (*b*) name one method used for overcoming the problem.

101 State the main difficulty you would expect to have to overcome in joining each of the following types of material by gas-shielded tungsten-arc welding:
(*a*) malleable cast iron,
(*b*) solution-treatable aluminium alloy.

102 (*a*) Name any *two* limitations of the gas-shielded tungsten-arc welding process.
(*b*) Name any *two* limitations of the gas-shielded metal-arc welding process.
(*c*) Why is a gas shield needed in the two types of arc processes in which it is used?

103 (*a*) In tungsten-arc welding how should the welding arc be initiated without contact between electrode and parent metal?
(*b*) With the aid of a simple line diagram show all the essential equipment for the conditions that you outline in (*a*) and clearly label each part.

104 (*a*) With the aid of sketches show how a single-vee butt joint preparation for tungsten-arc welding should differ from that of gas-shielded metal-arc welding in the same thicknesses of similar materials.

(*b*) Give the main reason why they should differ.

105 The support column shown in the figure is to be made up from 25 mm thick plates of high-strength low-alloy structural steel mounted on a square mild steel base plate. The sizes are given on the diagram.

(*a*) Outline the main material problems to be overcome in welding this construction.

(*b*) Indicate where you would locate the four transverse joints required to make up the vertical member from the two plates.

106 For the support column shown in the figure and the materials quoted in question, give

(*a*) the details of the appropriate longitudinal joint preparation used to complete the hollow section,

(*b*) the number and sequence of deposition of the runs required to complete the section,

(*c*) any precautions necessary to ensure sound welds.

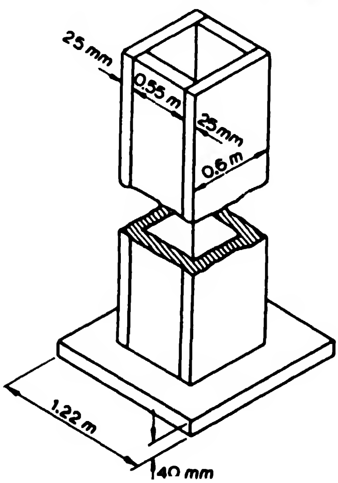
107 For the support column shown in the figure and the materials quoted in question, give

(*a*) the details of the appropriate joint preparations used to attach the vertical member to the base,

(*b*) the number and sequence of deposition of runs used to complete this joint,

(*c*) any precautions necessary to ensure sound welds.

Questions 105–108. Overall height 5.6 m. Material available for main stem: plate 3.5 m × 1.2 m × 25 mm, plate 2.0 m × 1.2 m × 25 mm.
Note. Gas shielded metal arc welding to be used for all except tack welds.



108 Discuss the main factors affecting the desirability of making up a special welding fixture for use when making the longitudinal welds in the vertical member of the support column shown in the figure.

109 (*a*) Give *two* reasons why it is necessary to be particularly careful of plant insulation when using HF current.
(*b*) Why may it be dangerous to weld with an exposed arc near to a tank filled with non-flammable degreasing liquid?

110 (*a*) Give the principle reason why carbon dioxide gas is used for the gas-shielded metal-arc welding of mild steel.
(*b*) Give *one* specific difficulty to be overcome when using carbon dioxide as a shielding gas for arc welding mild steel.

111 With the aid of an outline sectional sketch show the relative positions and proportions of (*a*) the electrode, (*b*) the collet, (*c*) the gas entry and (*d*) the nozzle, in a typical gas-shielded tungsten-arc welding torch head.

112 On a simple outline sketch locate and name the function of any *three* parts essential to the operation of the welding head of a fully automatic gas-shielded metal-arc welding plant.

113 Give any *three* possible differences between the respective preparation and deposition techniques for making a flat single V butt weld in 12 mm thick material by (*a*) gas-shielded tungsten-arc welding and (*b*) gas-shielded metal-arc welding.

Other welding processes

1 (*a*) Explain *four* principles involved in the production of a weld.
(*b*) State *four* variables which influence the production of friction welds.

2 The electroslag process is used for a wide range of welded work.
(*a*) Outline the principles of this process.
(*b*) Sketch a sectional view of the weld area during welding showing all the essential parts.
(*c*) Explain how the joint may be set up to retain its shape and minimize transverse shrinkage.
(*d*) State *three* reasons why run-on and run-off plates are required.
(*e*) Describe a suitable method of testing the weld metal to assess its toughness.
(*f*) Describe a heat treatment process that can be used to improve the toughness of the completed welded joint.

3 (*a*) Explain how heat is produced in the resistance spot welding process.

(*b*) The figure shows a time, pressure, current diagram which illustrates the sequence of operations for the formation of a resistance spot weld.

(1) Calculate the percentage of the total time during which the current flows to form the weld.

(2) Calculate the total heat energy generated in joules using the formula $J = I^2 Rt$, where
I = current in amperes,
R = 0.001 ohm resistance,
t = time in seconds,
J = heat energy.

4 (*a*) Explain *four* principles involved in the production of a friction weld.

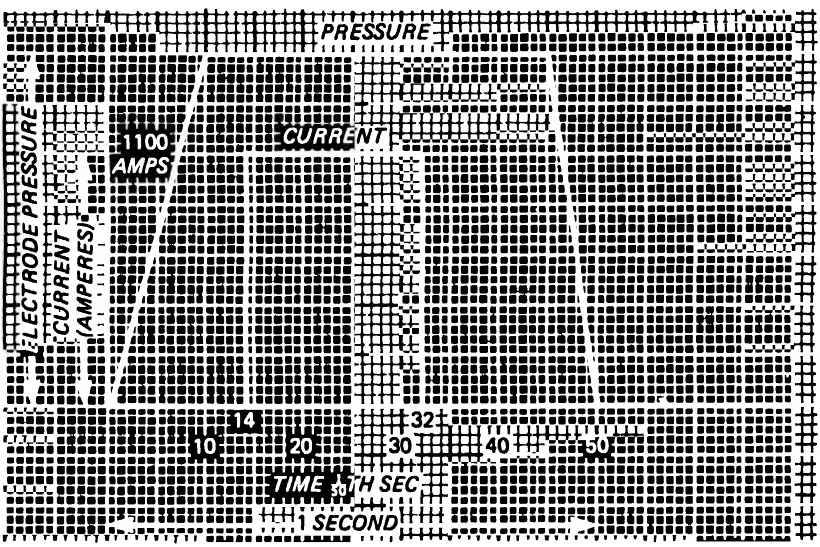
(*b*) State *four* variables which influence the production of friction welds.

5 For each of three of the following give a description of (1) the principles of operation, (2) a typical application:

(*a*) submerged arc welding.
(*b*) electric resistance spot welding,
(*c*) electroslag welding,
(*d*) arc stud welding.

6 With the aid of sketches show how resistance projection welding differs from resistance spot welding.

Question 3



7 Describe briefly the principles of operation, and give *one* suitable industrial application, for *three* of the following welding processes:
   (*a*) electroslag,
   (*b*) electric resistance flash butt,
   (*c*) electron beam,
   (*d*) friction.

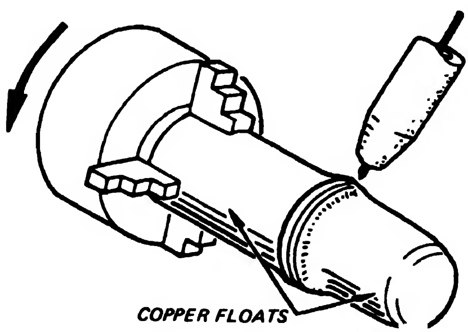
8 The figure shows a fixture arrangement for the automatic arc welding of copper floats using the gas-shielded tungsten-arc process.
   (*a*) State the influence the thermal conductivity of the metal would have on weld penetration.
   (*b*) State *three* factors other than thermal conductivity which would influence weld profile.

9 (*a*) List the following welding processes in their order of usefulness for welding steel components 50 mm thick, in the vertical position:
      (1) arc welding with coated electrodes,
      (2) electron beam welding,
      (3) electroslag welding,
      (4) laser beam welding.
   (*b*) Give a brief outline of friction welding.

10 (*a*) Explain why a flux is not required for resistance spot welding.
   (*b*) Give *three* possible causes of defective resistance spot welds.

11 The submerged arc welding process is used for a wide range of welded work.
   (*a*) Outline the principles of this process.
   (*b*) Explain why run-on and run-off plates are used.
   (*c*) State the purpose of vacuum recovery.

Question 8



(*d*) State *four* precautions to be taken in order to avoid porosity of the welded joint.
(*e*) State *four* advantages this process has over the manual metal-arc process.

Cutting processes

1 (*a*) State *two* methods used for gas cutting bevels on plate edges in preparation for welding.
(*b*) Describe, with the aid of a sectional sketch indicating the gas paths, the operation of an oxy-fuel gas cutting blowpipe.

2 (*a*) Make labelled sketches to show the essential difference between the nozzle assemblies used with
(1) acetylene,
(2) propane,
for the oxy-fuel gas cutting of low-carbon steel.
(*b*) After manual oxy-fuel gas cutting 50 mm thick low-carbon steel, it is required to cut 6 mm thick low-carbon steel plate. State the adjustment which will need to be made for this operation to be efficiently carried out.

3 Explain the action which produces the severance of the metal when oxy-fuel gas cutting low-carbon steel and state the difference between the basic principles of gas cutting and flame gouging.

4 (*a*) Give three operations which are essential during the assembly of a high-pressure oxy-acetylene cutting plant to ensure safe and effective service.
(*b*) Show by means of labelled sketches the angles of slope and tilt of the electrode when making a straight cut in 8 mm thick low-carbon steel plate in the flat position by the air-arc process.

5 (*a*) What is meant by 'oxygen lance cutting'? Give *two* examples of its use.
(*b*) Describe with the aid of sketches the technique required when cutting low-carbon steel-plate in the flat position by the use of each of the following arc cutting processes:
(1) air-arc,
(2) oxygen arc.

6 Unsuitable variations during oxy-fuel gas cutting of steel may lead to faults along the cut face. Show, by means of labelled sketches of the cut face, the faults which would be caused by either:
(1) the speed of travel being too fast, or

(2) the nozzle being too high above the work surface.

7 (*a*) Explain how the correct size of cutting nozzle to be used in the oxy-fuel gas cutting process should be determined.

(*b*) Discuss the influence on the oxy-fuel gas cutting operation of any two alloying elements which may be present in the steel.

(*c*) Describe how cast iron can be cut by the oxy-fuel gas cutting process.

8 (*a*) Explain the action which causes the severance of the metal when using the oxy-fuel gas cutting process for the cutting of austenitic stainless steel.

(*b*) What is meant by stack cutting? List *two* advantages of the use of stack cutting.

9 (*a*) Give *two* advantages in *each* case which may be obtained when oxy-fuel gas cutting:

(1) manually,

(2) by machine.

(*b*) Describe, with the aid of a sketch, a suitable arc cutting process for the cutting of ferrous and non-ferrous metals.

10 (*a*) What is arc plasma?

By means of a simple labelled outline diagram, show one method of using arc plasma for cutting purposes.

(*b*) Explain the differences between

(1) a single port nozzle,

(2) a multi-port nozzle as used with plasma arc cutting.

(*c*) Show, by means of diagrams, the finished cut that is produced by each of these nozzles after cutting 4.5 mm thick austenitic stainless steel.

11 The following thermal cutting equipment is available for use:
oxy-acetylene manual cutting equipment,
arc plasma profile cutting machine,
oxy-acetylene cutting equipment complete with lance,
oxy-acetylene cutting equipment complete with dispenser unit.
From the cutting equipment available select, with reasons, which cutting process should be used for cutting each of the following materials to the shape or form specified. Do not use the same process for cutting both materials.

(1) 200 mm diameter discs to be cut from 20 mm thick austenitic stainless steel plate.

(2) The removal of excess material from a newly cast grey iron casting.

(3) Outline the principles of the thermal cutting process used.
(4) State *two* aspects of safety that are particularly appropriate to each process used.

12 State why the arc plasma process would be used in preference to oxygen and fuel gas cutting of austenitic stainless steel.

13 (*a*) Why is it necessary to pre-heat medium- and high-carbon steels before cutting by the oxy-fuel gas cutting process?
(*b*) State the factors that prevent the use of natural gas as an oxy-fuel cutting gas.

14 (*a*) Discuss the health hazards that can be encountered when cutting galvanized steel sheet.
(*b*) State the safety precautions that should be adopted to ensure that workshop personnel can be protected against these hazards.

15 (*a*) Describe two suitable thermal cutting processes which could be used to cut 1 metre diameter blanks from 12 mm thick austenitic steel plate.
(*b*) Compare the *two* methods selected in (*a*) with regard to:
(1) cost,
(2) speed of cutting,
(3) distortion,
(4) treatment after cutting.

16 (*a*) List the following cutting process in sequence with regard to best quality of cut face for the thermal cutting of austenitic stainless steel 38 mm thick in the flat position:
(1) oxygen-arc,
(2) air-arc,
(3) oxy-fuel-gas powder,
(4) arc-plasma.
(*b*) Explain, with the aid of a sketch, how the heat is produced for cutting by the plasma cutting process.

17 (*a*) Explain briefly the principles of *laser cutting*.
(*b*) List the advantages of laser cutting over conventional methods of cutting such as oxy-fuel gas and oxy-arc cutting.

Oxy-acetylene

(*a*) State *four* problems associated with the welding of copper.
(*b*) State what type of flame setting should be used and how it is attained.
(*c*) Describe in detail the welding procedure.

2 (*a*) Unsuitable variations during oxy-fuel gas cutting of steel may lead to faults along the cut face. Show, by means of labelled sketches of the cut face, the faults which would be caused by *either*
   (1) the speed of travel being too fast, *or*
   (2) the nozzle being too high above the work surface.
(*b*) State *two* methods which may be used for back gouging the root, ready for a sealing run, on the reverse side of welded butt joints in low-carbon steel.

3 Describe briefly the fundamental differences between the following: (*a*) the technique for the bronze welding of cast iron, and (*b*) the technique for the fusion of welding of cast iron.

4 (*a*) Describe, with the aid of sketches, the all-position rightward technique to be used when making a butt joint in low-carbon steel pipe 100 mm diameter by 5 mm wall thickness, the pipe axis to be in the fixed vertical position throughout.
(*b*) Compare the respective advantages and limitations of the leftward and the rightward techniques when used for the butt welding of low-carbon steel plate, 5 mm thick, in the flat position.

5 (*a*) Describe briefly, with the aid of a sectional sketch and indicating the gas paths, the mode of operation of *either*
   (1) a non-injector type welding blowpipe, *or*
   (2) a single-stage gas pressure regulator.
(*b*) What precautions are necessary during the assembly of a high-pressure oxy-acetylene cutting plant in order to ensure safe and effective operation?
(*c*) Explain why the specified discharge rate of a dissolved acetylene cylinder must not be exceeded when in use.

6 (*a*) Describe in detail, with the aid of sectional sketches, *four* defects which may occur during the oxy-acetylene welding of low-carbon steel, stating in *each* case its cause and explaining how it may be avoided.

7 Describe the technique necessary to form a tee-fillet joint in 1.6 mm commercially pure aluminium sheet by the flame brazing process.
State the type of filler wire and flame setting needed. You may use a sketch to illustrate your answer.

8 (*a*) Name three impurities found in acetylene gas immediately after generation.
(*b*) Explain how acetylene gas may be tested for purity.

9 (*a*) Summarize the problems encountered in the oxy-acetylene repair welding of each of the following cast materials: (1) zinc base die cast alloy, (2) magnesium alloy.
(*b*) Describe the preparation, welding technique and post-weld treatment necessary for each.

10 (*a*) When would a carburizing flame be used for joining metals?
(*b*) What purpose is served by the use of such a flame adjustment?

11 Describe, with the aid of a simple outline sketch, one example of a repair welding operation where *studding* could be employed with advantage.
(*a*) Name two advantages of using a high silicon content in cast iron, or in cast iron filler rods for welding purposes.
(*b*) Give the approximate percentage of silicon contained in a 'super-silicon' cast iron filler rod.

12 (*a*) What is meant by the term 'hard-facing'?
(*b*) Name two types of filler rod that may be used for hard-facing operations.

13 (*a*) Name the fuel gas generally used for underwater flame cutting operations.
(*b*) State one good reason why this gas is used.

14 (*a*) Explain, in detail, four safety measures that should be taken before carrying out welding repairs on a 150 litre (30 gallon) low-carbon steel petrol tank.
(*b*) Describe the hazards encountered when welding galvanized metals. State the precautions to be taken in the interests of health and safety.

15 A 6 mm thick magnesium alloy casting is cracked for a length of 150 mm and is to be repaired by oxy-acetylene welding.
(*a*) Outline the preparation which may be required before welding.
(*b*) Give *two* methods of indicating the correct pre-heat temperature.
(*c*) Describe a suitable method of stress relieving after welding.
(*d*) Explain how the flux residue should be removed.

16 A cobalt-based, hard-facing alloy is required to be deposited on to a low-carbon steel component.
(*a*) State how the component could be prepared.
(*b*) Name the type of flame setting required for a single layer deposit and give *two* reasons for your choice.

(*c*) State *two* precautions to be taken to avoid defects.

17 What is the included angle of preparation necessary for single-vee butt welded joints to be made by the oxy-acetylene process using (1) the leftward technique, and (2) the rightward technique?

18 (*a*) What is meant by 'all-position rightward welding'?
(*b*) Give two important advantages which may be obtained by the use of this technique for the welding of pipe joints.

19 (*a*) Explain briefly how (1) carburizing and (2) oxidizing oxy-acetylene flame settings are obtained.
(*b*) Give one important application of each flame setting.

20 What is the purpose of (*a*) portable cylinder couplers in oxy-acetylene welding, (*b*) a brushless d.c. generator for metal-arc welding?

21 (*a*) Make a labelled section-sketch to show the arrangement of the nozzle assembly used for progressive flame gouging.
(*b*) State two methods used for gas-cutting bevels on plate edges in preparation for welding.

22 Name one possible cause of each of the following, when oxy-acetylene welding butt joints in mild steel: (*a*) excessive penetration, (*b*) incomplete penetration, (*c*) adhesion.

23 (*a*) What is the difference between a backfire and a flashback?
(*b*) Name five possible causes of backfiring when using a gas welding blow-pipe. In each case explain how backfiring could have been avoided.
(*c*) State two difficulties which may be experienced in the efficient operation of a gas pressure regulator.
(*d*) State the purpose of each part of the high-pressure oxy-acetylene welding system.

24 Sketch the joint preparation and set-up, and state the nozzle size (in cubic feet or litres per hour) and filler rod size to be used, for making: (1) butt welds in the vertical position in each of the following thickness of mild steel: 3.2 mm ($\frac{1}{8}$ in.) and 5 mm ($\frac{3}{16}$ in.); (2) a tee fillet-weld in the horizontal vertical position in 5 mm ($\frac{3}{16}$ in.) thick mild steel plate.
Describe in detail, with the aid of sketches, the fusion welding of a butt joint in cast iron 10 mm ($\frac{3}{8}$ in.) thick.

25 Explain what is meant by gas velocity and outline how this is controlled in welding practice.

26 Describe, with the aid of a sectional sketch indicating the gas paths, the operation of an oxy-fuel gas cutting blowpipe.

27 (*a*) Sketch the joint preparation and set-up and state the nozzle and filler rod sizes to be used for making:

(1) a butt weld in the vertical position in 3 mm thick low-carbon steel,

(2) a close-square tee fillet weld in the horizontal vertical position in 5 mm thick low-carbon steel,

(3) a fusion welded butt joint in the flat position in 10 mm thick cast iron.

(*b*) Describe in detail, with the aid of sketches, the procedure and the technique required for making any *one* of the joints in part (*a*) above.

28 Outline one method which may be used during the oxy-acetylene welding of vertical butt joints, in 4 mm thick low-carbon steel, to ensure freedom from weld defects when

(*a*) starting the weld at the beginning of the joint,

(*b*) restarting the weld at a stop-point along the joint.

29 State *two* safety precautions which should be taken for *each* of the following:

(*a*) storage or use of dissolved acetylene cylinders,

(*b*) using gas pressure regulators,

(*c*) oxy-acetylene cutting operations in a confined space,

(*d*) using non-injector type gas welding blowpipes.

30 (*a*) Explain the action which produces the severance of the metal when oxy-fuel gas cutting low-carbon steel and state the difference between the basic principles of gas cutting and flame gouging.

(*b*) Describe, with the aid of a sectional sketch indicating the gas paths, the operation of an oxy-fuel gas cutting blowpipe.

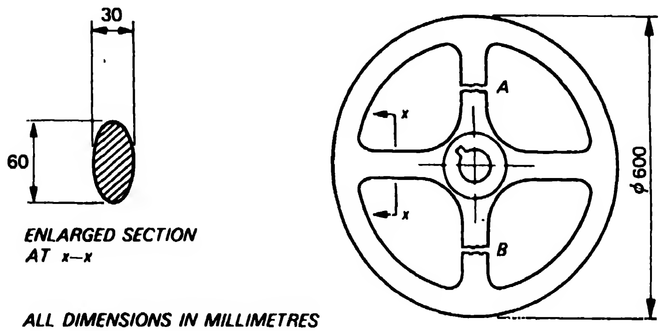
31 Explain what is meant by capillary attraction and describe how this affects the making of certain brazed joints.

32 The figure shows a cast iron wheel with two broken spokes. With the aid of a sketch, indicate how partial pre-heating may be used to minimize the risk of cracking.

33 (*a*) Describe with the aid of sketches the technique for making a lap fillet weld in the horizontal-vertical position by the oxy-acetylene process.

(*b*) Compare the respective advantages and limitations of the leftward and the Lindewelding techniques when butt welding mild steel pipes.

Question 33



Multiple choice

Note: The following are examples of the multiple choice type of question but may not be representative of the entire scope of the examination either in content or difficulty.

1 Because of the possibility of explosions, acetylene line fittings should *not* be made from

(*a*) steel
(*b*) copper
(*c*) aluminium
(*d*) cast iron.

2 One reason why low-carbon steel may be successfully welded by oxy-acetylene without the use of a flux, is that the oxide

(*a*) is under the surface
(*b*) has a higher melting point than the parent metal
(*c*) has a lower melting point than the parent metal
(*d*) melts at the same temperature as the parent metal.

3 An undesirable property of an aluminium flux residue is that it
 (*a*) is corrosive
 (*b*) obstructs the vision of the molten pool
 (*c*) decreases fluidity
 (*d*) requires great heat to melt it.

4 When a low-alloy steel has a hard and brittle structure it may be rendered soft and malleable by
 (*a*) recrystallization
 (*b*) cold working
 (*c*) lowering its temperature
 (*d*) hot quenching.

5 What happens to the mechanical properties of steel if the carbon content is increased to 0.5%?
 (*a*) The material becomes softer.
 (*b*) Malleability is increased.
 (*c*) The tensile strength is increased.
 (*d*) Ductility is increased.

6 The main reason for pre-heating medium- and high-carbon steels before cutting by the oxy-fuel gas technique is to
 (*a*) improve the quality of cut
 (*b*) increase the cutting speed
 (*c*) refine the grain structure
 (*d*) prevent hardening and cracking.

7 Which one of the following factors restricts the use of town gas as an oxy-fuel cutting gas?
 (*a*) Its low calorific value.
 (*b*) Its tendency to cause rapid melting.
 (*c*) Its unsuitability for cutting plates less than 12 mm thick.
 (*d*) Its relatively high cost.

8 A suitable filler wire for brazing pure aluminium would consist of:
 (*a*) aluminium bronze
 (*b*) aluminium alloy containing 10/13% silicon
 (*c*) aluminium alloy containing 5% magnesium
 (*d*) pure aluminium.

9 Columnar growth takes place when a metal is
 (*a*) cold
 (*b*) losing heat
 (*c*) being heated
 (*d*) being rolled.

10 Difficulty may be encountered when welding aluminium because
 (*a*) the weld metal expands during solidification

(*b*) its coefficient of expansion is low compared to steel
(*c*) no colour change takes place to indicate its melting points
(*d*) its thermal conductivity is low compared to steel.

11 One purpose of a microscopic examination of a weld is to establish the
(*a*) strength of the weld
(*b*) number of alloying elements
(*c*) grain size
(*d*) number of runs used.

12 Which one of the following components is employed to control amperage in an a.c. arc-welding circuit?
(*a*) rheostat
(*b*) choke
(*c*) voltmeter
(*d*) resistor.

13 When carrying out welds in low-carbon steel, using the carbon dioxide welding process, one purpose of the inductance control is to reduce
(*a*) porosity
(*b*) penetration
(*c*) undercut
(*d*) spatter.

14 One purpose of a reactor (choke) when manual metal arc welding is to
(*a*) change alternating current to direct current
(*b*) allow the correct amperage to be selected
(*c*) allow the desired arc voltage to be selected
(*d*) enable the correct polarity to be chosen.

15 Which shielding gas is generally recommended when butt-welding 6 mm nickel alloy sheet by the metal-arc gas-shielded process?
(*a*) Argon
(*b*) CO_2
(*c*) Hydrogen
(*d*) Nitrogen.

16 When TIG welding using a.c. output, which one of the following is essential in the circuit to stabilize the arc?
(*a*) A surge injector
(*b*) An open circuit voltage of 100 volts
(*c*) A flow meter
(*d*) An amperage regulator.

17 In manual metal-arc welding the flux coating to give deep penetration characteristics would contain
- (*a*) iron oxide
- (*b*) manganese
- (*c*) cellulose
- (*d*) calcium carbonate.

18 Which element is used as a deoxidant in copper filler rods?
- (*a*) Aluminium
- (*b*) Tin
- (*c*) Sulphur
- (*d*) Phosphorus.

19 An oxygen cylinder regulator being used in a flame-cutting supply may freeze up if the
- (*a*) gas withdrawal rate is exceeded
- (*b*) cylinder content is too low
- (*c*) cylinder is on its side
- (*d*) needle valve on the regulator is not fully open.

20 To test a component part for a vibrational loading, a suitable mechanical test would be
- (*a*) impact
- (*b*) tensile
- (*c*) compressive
- (*d*) fatigue.

21 The principal advantage of arc-on-gas welding is that it
- (*a*) allows controlled penetration of initial bead
- (*b*) requires less operator skill
- (*c*) entirely eliminates distortion
- (*d*) improves surface finish.

22 One reason why a grey cast iron casting should be slowly cooled after welding is to keep it
- (*a*) soft
- (*b*) spheroidal
- (*c*) hard
- (*d*) brittle.

23 An iron casting has a crack in it. Before oxy-acetylene fusion welding it may be necessary to drill the ends of the crack. One reason for this is to
- (*a*) balance out any shrinkage stresses
- (*b*) stop the crack from spreading
- (*c*) prevent the ends of the crack from being carburized
- (*d*) prevent grain growth.

24 Which one of the following metals may require the studding

techniques to be used when being repaired by manual metal arc welding?
  (*a*) Low-carbon steel
  (*b*) Aluminium
  (*c*) Nickel
  (*d*) Cast iron.

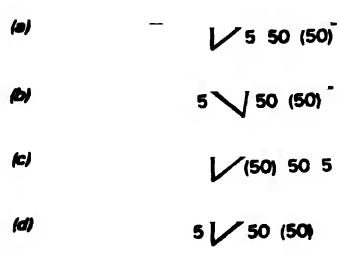
25 During the deposition of a manual metal-arc electrode, a certain percentage of the core wire is lost. This is due to
  (*a*) voltage drop across the arc
  (*b*) short arc length
  (*c*) spatter
  (*d*) excessive build-up.

26 Which one of the following can be welded by d.c. using the tungsten arc gas-shielded process?
  (*a*) Copper
  (*b*) Commercial pure aluminium
  (*c*) Silicon–aluminium
  (*d*) Magnesium alloys.

27 Backing bars for manual metal-arc welding of low-carbon steel should be made from
  (*a*) copper
  (*b*) low-carbon steel
  (*c*) tool steel
  (*d*) cast iron.

28 Peening may be carried out when manual metal-arc welding cast iron in order to
  (*a*) reduce the effects of contraction
  (*b*) make the bond more firmly adhering
  (*c*) refine the grain structure
  (*d*) speed up the welding.

29 The fillet welds on the support brackets in the figure should have 5 mm leg length with 50 mm intermittent welds as shown. The symbol at *A* to communicate this information should be



30 What is the volume of deposited metal in a fillet weld indicated by the symbol in the figure neglecting reinforcement?

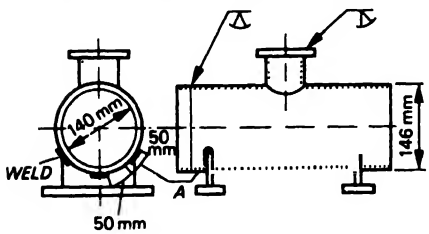
(*a*) 14000 mm^3

(*b*) 14900 mm^3

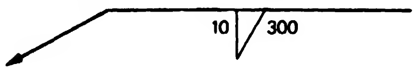
(*c*) 15000 mm^3

(*d*) 15 100 mm^3.

Question 29. The figure shows a component fabricated from stabilized austenitic stainless steel sheet 3 mm thick.



Question 30



Answer key

1 – *b*	11 – *c*	21 – *a*
2 – *c*	12 – *b*	22 – *a*
3 – *a*	13 – *b*	23 – *b*
4 – *a*	14 – *b*	24 – *d*
5 – *c*	15 – *a*	25 – *c*
6 – *d*	16 – *a*	26 – *a*
7 – *a*	17 – *c*	27 – *b*
8 – *b*	18 – *d*	28 – *a*
9 – *b*	19 – *a*	29 – *d*
10 – *c*	20 – *d*	30 – *c*

Welding engineering craft studies

All dimensions are in millimetres

1 Spot welds are to be made by the tungsten arc gas-shielded welding process.

(*a*) Make a sectional sketch through one of these spot welds.

(*b*) State *one* advantage that this process has over the resistance spot welding process for making this type of weld.

(*c*) Name the additional equipment that would be necessary for making the spot welds using standard tungsten arc gas-shielded welding equipment.

2 (*a*) How is the size of a fillet weld with normal penetration determined in accordance to BS 499 in

(1) a convex fillet weld,

(2) a concave fillet weld?

(*b*) Make a sectional sketch of a mitre fillet weld.

3 State *five* factors that would influence the pre-heating temperature to be used for a welded steel fabrication.

4 (*a*) Give *two* reasons why hydrogen-controlled electrodes are preferred for manual metal-arc welding restrained joints in low-alloy steel.

(*b*) Explain the influence of the cellulose in the coating of an electrode on

(1) voltage,

(2) penetration.

5 A circular low-carbon steel plate of 750 mm in diameter and 10 mm thick has to be fitted and welded into a deck plate.

(*a*) State why hot cracking is likely to occur in this particular type of assembly.

(*b*) Outline *either* a suitable weld sequence *or* a change in the form of the plate insert that could be used to avoid the occurrence of hot cracking.

6 A worn press die has to be built up using the oxy-acetylene flame powder spraying process.

(*a*) From the table select the powder to be used for this repair.

(*b*) List *three* advantages that powder spraying has over arc welding for this type of repair.

(*c*) Name the type of flame setting to be used.

Powder no.	Resistance to: Abrasion	Impact	Machinability
1	Fair	Excellent	Very good
2	Very good	Excellent	Very good
3	Excellent	Poor	Grind only

7 From the information given below, list in the correct order the welding sequence that should be carried out when friction welding two 20 mm diameter low-carbon steel bars.

(*a*) Place parts lightly in contact.
(*b*) Load machine.
(*c*) Apply axial force.
(*d*) Apply upset force.
(*e*) Rotate chuck and close gap.
(*f*) Release upset force.
(*g*) Arrest chuck movement.
(*h*) Remove specimen.

8 Steel cylindrical tanks 5 m long and rolled to 2 m internal diameter from 50 mm thick low-carbon steel plate are to be welded, using the electroslag welding process for the longitudinal seams.

(*a*) With the aid of a sketch outline how the weld area is protected from atmospheric contamination.
(*b*) (1) State *three* advantages that the electroslag welding process has over arc welding processes for welding process for the longitudinal seams.
(2) Give *two* limitations of the electroslag welding process.
(*c*) (1) What is the purpose of run-on and run-off plates when electroslag welding?
(2) After electroslag welding has commenced small additions of flux must continue to be added to the weld pool. Why is this?
(*d*) If it was considered that the cylinder would be working under conditions that may cause stress corrosion cracking:
(1) State what is meant by the term stress corrosion cracking,
(2) State *two* precautions that could be taken to reduce the occurrence of failure from this form of attack.

9 The figure shows a low-carbon steel nut to be resistance projection welded to 2 mm thick low-carbon steel sheet.

(*a*) Explain the principles involved in making this welded connection using the resistance welding process.
(*b*) Make a sectional sketch through *A–A* of the welded assembly shown in the figure.
(*c*) State *two* advantages of resistance welding over manual metal-arc welding for making this welded connection.
(*d*) List *three* defects that may be found when resistance *spot*

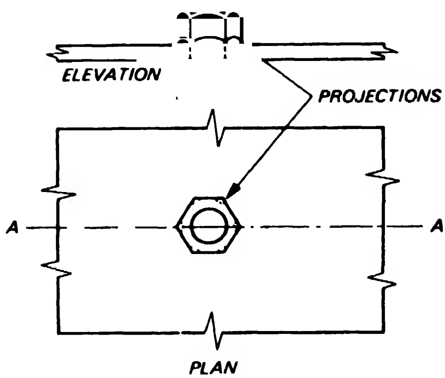
welding, and in each case state the probable cause of the defect.

10 As part of a welding sequence, stiffeners require to be welded to the aluminium alloy plate shown in the figure.

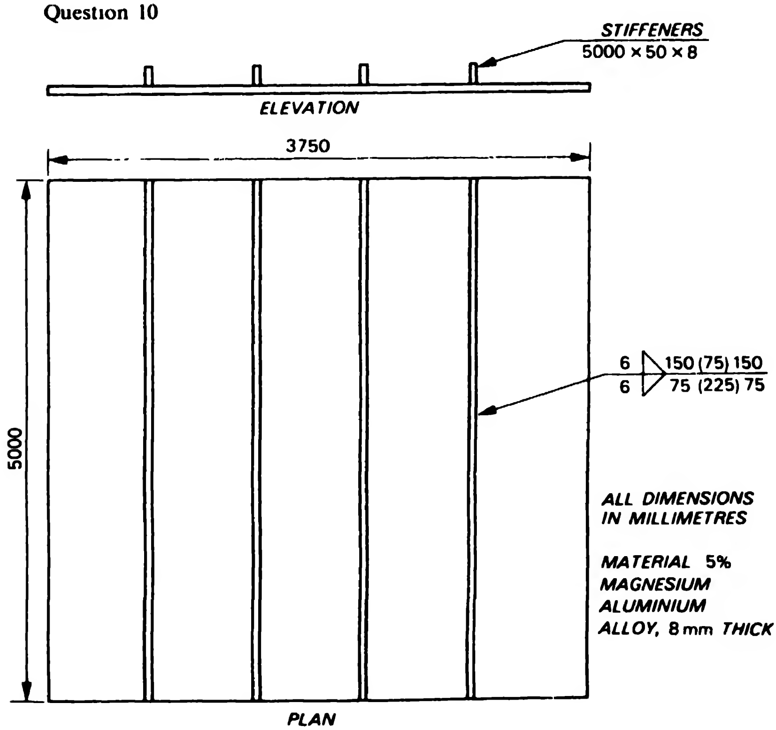
(*a*) Select a suitable process for welding the stiffeners.

(*b*) Sketch and label the essential components of the welding circuit for the process selected.

Question 9



Question 10



(*c*) Using a graph to illustrate your answer, give a brief outline of the output characteristics of the power source needed for the process used.

(*d*) What information is indicated by the weld symbol shown in the drawing?

11 Alloy steel of the following % composition has to be manual metal-arc welded.

Carbon (C)	Chromium (Cr)	Molybdenum (Mo)	Manganese (Mn)	Silicon (Si)	Nickel (Ni)	Vanadium (V)
0.16	1.5	0.5	0.8	0.4	0.0	0.0

Remainder: iron with acceptable limits of impurities.

(*a*) State *three* advantages of using alloying elements in steel.

(*b*) (1) Using the carbon equivalent formula given below determine the carbon equivalent of the alloy steel outlined above.

Carbon equivalent (%) =

$$C\% + \frac{Mn\%}{20} + \frac{Ni\%}{15} + \frac{Cr\% + Mo\% + V\%}{10}$$

(2) Indicate how the information produced may be used to determine the welding procedure used.

(*c*) Explain why pre-heating this alloy may reduce the occurrence of underbead cracking.

(*d*) Welds made on low-alloy steels are generally heat treated by normalizing.

(1) What is meant by normalizing?

(2) State *three* advantages produced by normalizing welded fabrications.

12 State *five* factors that will influence dilution during fusion welding.

13 (*a*) Give *three* reasons for pre-heating air-hardenable steels before or during oxy-fuel gas cutting.

(*b*) Give the main constituents in an air-hardenable steel.

14 Briefly explain how a friction weld is produced.

15 (*a*) State *three* advantages of using fully automatic welding processes in preference to manual welding processes.

(*b*) Under what circumstances may manual welding be preferred to fully automatic welding?

16 (*a*) Explain how heat is produced during cutting when using the oxygen lance.

(*b*) State *two* safety precautions that should be taken when using the oxygen lance for cutting.

17 List *five* problems which may be encountered when fusion welding aluminium.

18 Explain briefly why single-pass welds made by the arc plasma process may have the form shown in the macrograph in the figure.

19 One thousand circular containers as shown in the figure have been fabricated from low-carbon steel by using the metal-arc gas-shielded welding process with carbon dioxide as shielding gas.

  (*a*) Name the main type of stress, in *each* case, that weld *A* and *B* would be subjected to during hydraulic testing.

  (*b*) During testing some welds were found to contain porosity. State *three* probable causes of this defect.

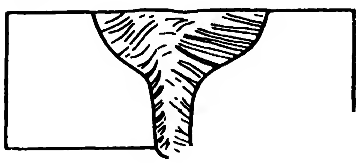
20 (*a*) The figure shows a time and current graph making an electric resistance spot weld. The following two parts of this question refer to this diagram.

  (1) Calculate the weld time as a percentage of the welding cycle.

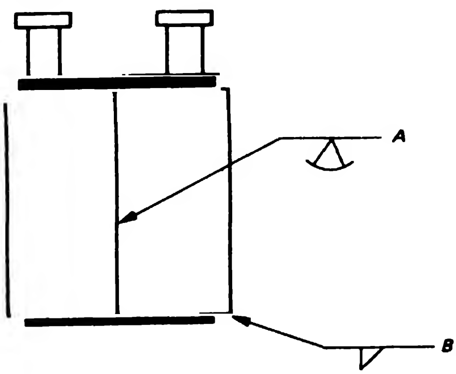
  (2) Explain why it is generally necessary for the forging time to be longer than the squeeze time.

(*b*) A resistance spot welding machine was set up for welding low-carbon steel. If austenitic stainless steel of the same

Question 18



Question 19



thickness is to be welded, what alterations would require to be made to

(1) the welding current,

(2) the welding time?

Explain why these alterations are necessary.

(*c*) Spot welding of sheet metal may also be carried out by fusion welding.

(1) Select a fusion welding process and describe how a spot weld is made using this process.

(2) What additional equipment would be necessary for making spot welds using standard equipment?

21 The figure shows a low-alloy steel rotary shear blade, used for trimming steel plate. The cutting edge has become worn due to severe abrasion during service and is to be repaired by using the manual metal-arc welding process.

(*a*) The general composition of three electrodes is shown below. Select the most suitable electrode for use in the building up of the cutting edge, and give a reason for your selection.

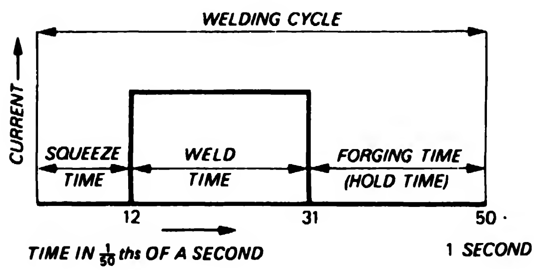
(1) Austenitic stainless steel.

(2) Medium-carbon low-alloy steel.

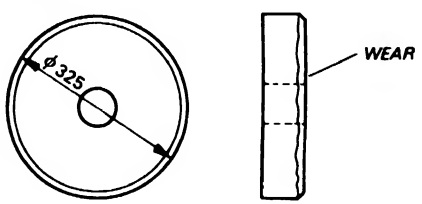
(3) Pure nickel.

(*b*) Outline the welding procedure that should be used to carry out this repair.

Question 20



Question 21



(*c*) Explain the influence that the dilution of the weld metal by the parent metal would have on the weld's mechanical properties.

(*d*) Under what circumstances would the oxy-acetylene welding process be preferred to arc-welding processes for hard surfacing?

22 The figure shows a low-carbon steel shaft to be fabricated by welding using the submerged arc welding process.

(*a*) With the aid of a sketch, explain how the weld area is protected from atmospheric contamination.

(*b*) State *three* advantages of using a backing strip for this joint.

(*c*) Sketch in detail the weld preparation that would be used for the butt weld shown at *A*.

(*d*) Why is the filler used in submerged arc welding copper coated?

(*e*) When submerged arc welding, explain why it is an advantage to use a multipower source which has one electrode using alternating current and the other direct current.

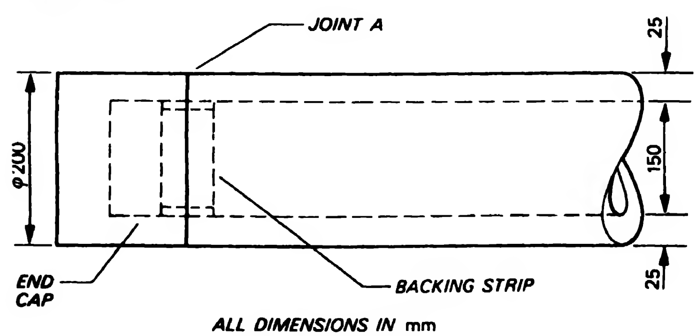
23 50,000 shear connectors are to be welded to the low-carbon steel box girder shown in the figure, using the drawn arc stud welding process.

(*a*) In what respect does the purpose-built power source used for this type of equipment differ from the power source used for metal-arc welding?

(*b*) Sketch in section, and label the main parts of, a ceramic ferrule used for stud welding.

(*c*) If the shear connectors are to be positioned at 100 mm centres, explain how this could be best achieved.

Question 22



(*d*) (1) Describe a method of testing the stud welds.
(2) Welds having the section shown in *d*(2) below failed during testing due to the defects shown. State *four* possible causes of these defects.

24 Power souces used for electron beam welding may be rated as 30 kV.
(*a*) Explain the term 30 kV.
(*b*) Give *two* reasons why electron beam welding is generally carried out in a vacuum.

25 (*a*) State *four* of the variables involved in the production of friction welds.
(*b*) State the range or temperature necessary for the production of friction welds in low-carbon steel.

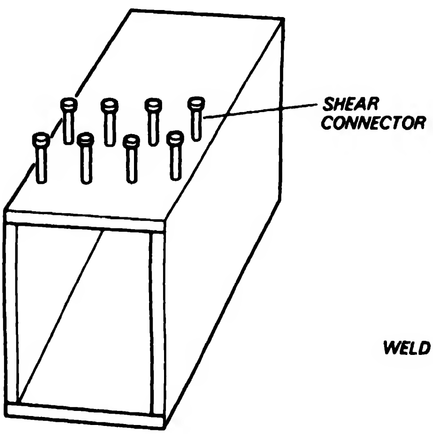
26 Sketch in section, and label the parts of, the head of an arc plasma torch for welding.

27 (*a*) State *three* advantages of introducing iron powder into the flame when oxy-acetylene powder cutting.
(*b*) State *two* hazards that the operator should guard against when oxy-acetylene powder cutting.

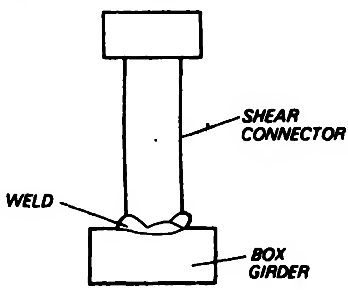
28 Low-carbon steel plate 25 mm thick has to be surfaced by the submerged arc welding process using stabilized austenitic stainless steel filler. List *five* variables that would influence the degree of dilution found in the weld.

29 Explain why it is recommended that materials containing sulphur should be removed from the weld area before welding nickel and nickel alloys.

Question 23



Question 23. (*d*) (2)



30 State *five* factors that would need to be considered before deciding the pre-heating temperature to be used on low-alloy steel plate.

31 (*a*) With the aid of a graph, explain why a constant potential power source is often preferred for automatic arc welding processes.

(*b*) List *four* variables, under the control of the welder, that can influence weld quality when using the submerged arc welding process.

(*c*) Explain why the quality of submerged arc welds made in low-alloy steels is particularly high compared with the quality of welds made by other arc welding processes.

(*d*) Inspection authorities may specify that welds made by the submerged arc welding process should be heat treated. Outline a suitable heat treatment.

32 The grey cast iron angle plate shown in the figure has to be repaired by manual metal-arc welding and then machined flush. Rutile-covered low-carbon steel and nickel alloy electrodes are available for making the weld.

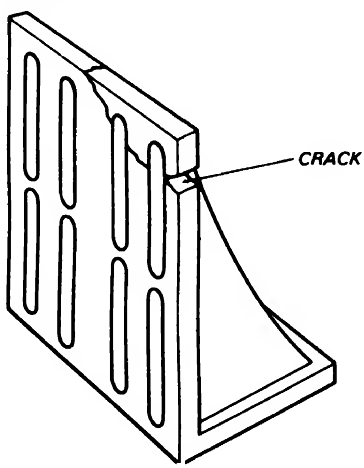
(*a*) Select the most suitable electrode to carry out this repair.

(*b*) State *two* advantages and *one* disadvantage of the electrode selected.

33 The aluminium-magnesium alloy components shown in the figure are to be welded using the metal-arc gas-shielded welding process.

(*a*) Explain why an argon/carbon dioxide gas mixture would be unsuitable as the gas shield to be used for welding the components.

Question 32



(*b*) State *three* factors that would influence the weld profile.

(*c*) Explain why the oxy-acetylene fusion welding process would be unsuitable for welding the components.

(*d*) Outline the influence that welding would have on the metal's mechanical properties and grain structure.

(*e*) If 1000 components are to be fabricated, calculate the total length of welding carried out to complete the contract. Each joint is to be made by means of a single-run weld deposit.

34 (*a*) Calculate the volume of metal deposited in the welded joint shown in the figure if the length of the joint is 10 m, and the total weld reinforcement is taken as one quarter of the total volume of the joint gap.

(*b*) Outline the influence of *each* of the following factors on the cost of welded fabrication:

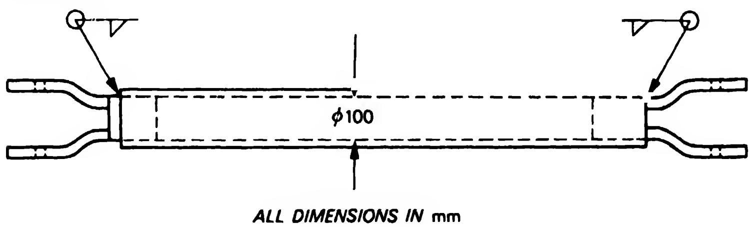
(1) current density,

(2) joint set-up.

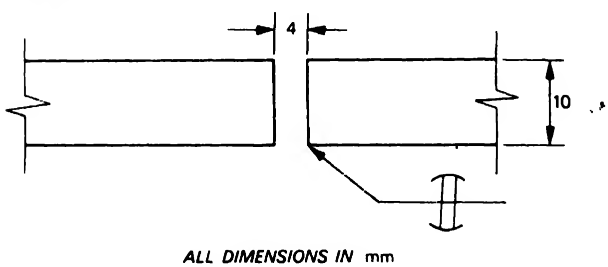
(*c*) Outline how *four* factors in the welding procedure can influence welding costs.

(*d*) Sketch an example of a non-load bearing fillet weld, indicating by an arrow the direction of the applied load on the component when in service.

Question 33



Question 34



35 A fabricated tank is to be manufactured from stabilized austenitic stainless steel. The weld preparation and holes are to be thermally cut using the arc plasma process.

(*a*) Explain why the arc plasma process would be used in preference to oxygen and fuel gas for cutting this material.

(*b*) Sketch in detail the design of the welded butt joint shown at *A* in the figure.

(*c*) State *two* problems which may be encountered during the arc welding of this joint.

(*d*) Explain why the depth of penetration would be greater in welds made in austenitic stainless steel, compared with similar welds made in low-carbon steel, assuming the energy input to be the same.

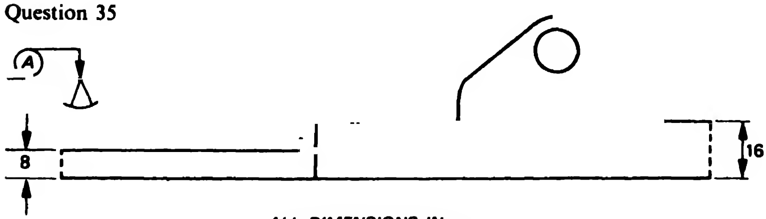
(*e*) Explain, with the use of a graph, why a drooping characteristic power source should be used when manual metal-arc welding, rather than a constant potential power source.

36 Component parts for an oil rig, having the form shown in the figure, are to be fabricated and joined by welding.

(*a*) Calculate the carbon equivalent of the steel given the following:

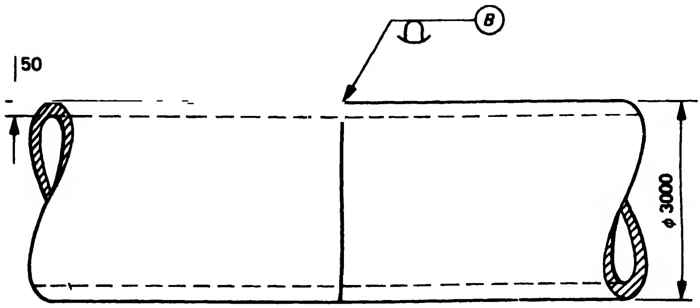
Material composition: Carbon, 0.22%; Silicon, 0.5%;

Question 35



ALL DIMENSIONS IN mm

Question 36



ALL DIMENSIONS IN mm

Manganese, 1.5%; Niobium, 0.1%; Vanadium, 0.1%; Sulphur, 0.05%; Phosphorus, 0.05%; remainder iron.

Carbon equivalent =

$$C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

(*b*) Sketch in detail the butt joint preparation shown at *B*.

(*c*) Outline a welding procedure that could be used to make the joint.

(*d*) Since this component will be subjected to fatigue conditions during service, state *three* precautions which should be taken when welding has been completed.

37 (*a*) The figure shows a cruciform welded joint. Using the formula $l = 1.4\, t$ calculate the throat size (t) of a fillet weld if the leg length (l) is 21 mm.

(*b*) Show by means of a labelled sectional sketch a fillet weld leg length of 21 mm.

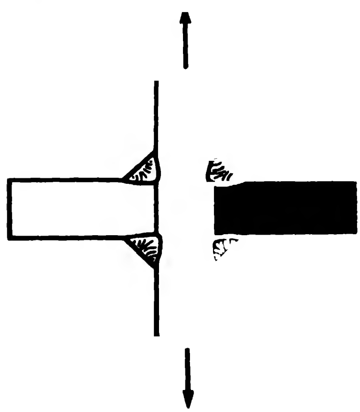
(*c*) A load is applied in the direction of the arrows indicated in the figure. State whether the welds are load bearing or non-load bearing.

(*d*) The material shown in the figure has a relatively high carbon equivalent and pre-heating temperatures have not been maintained during welding so that underbead cracking has resulted. Explain how the underbead cracking would take place.

(*e*) What is meant by the term 'fatigue fracture'?

(*f*) State *four* factors under the control of the welder which may adversely affect the fatigue life of a single-vee butt-welded joint.

Question 37



(*g*) State *three* precautions that could be taken to reduce the occurrence of a brittle fracture failure in a welded joint.

38 The figure shows an austenitic stainless steel hopper which has to be fabricated from 5 mm thick sheet.

(*a*) State *four* methods which may be used to ensure a low heat input procedure for arc welding the hopper.

(*b*) (1) State the value of the included angle *X* for the joint shown at *B*.

(2) State *two* reasons why the included angle *X* should be increased if welding has to be carried out.

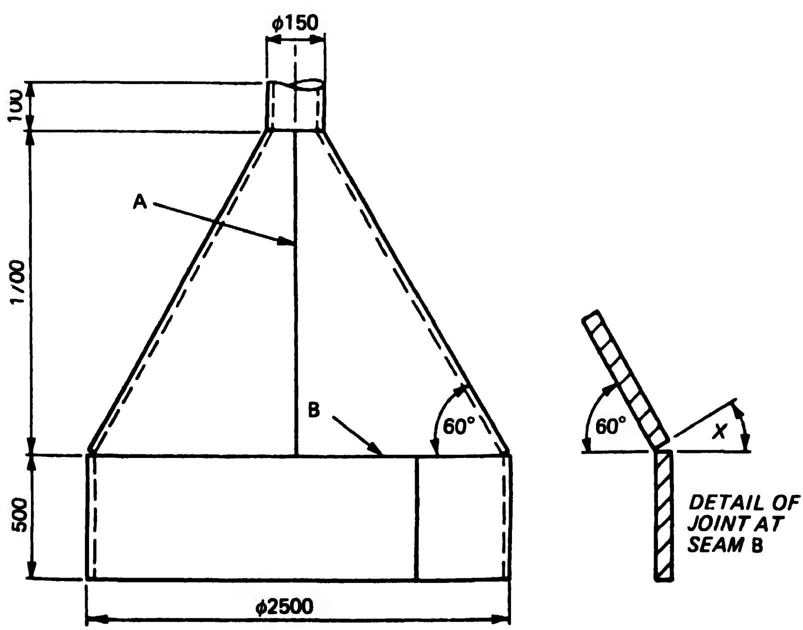
(*c*) Four different welding procedures could be used for making the butt-welded joints shown at *A* and *B*. State *one* advantage and *one* disadvantage for *each* of the following welding procedures.

(1) Completely weld the joints using the tungsten arc gas-shielded process.

(2) Completely weld the joints using the gas-shielded metal-arc process.

(3) Weld the first run using the tungsten arc gas-shielded process and complete the weld using the manual metal-arc process.

Question 38



(4) Completely weld the joints using the manual metal-arc process.

(*d*) (1) Explain why distortion is likely to be a problem when welding this material.

(2) Describe a method that could be used to control the distortion when welding joint *A*.

39 The figure shows a fabrication which is to be made from 25 mm thick low-carbon steel using the gas-shielded metal-arc welding process with flux cored electrode wire.

(*a*) Give *three* reasons why flux cored electrode wire may be preferred for welding this fabrication in preference to solid wire.

(*b*) State *two* advantages of using a gas shield in addition to the flux cored electrode wire when using this process.

(*c*) A root crack was observed when welding the single bevel butt weld joint shown in (*b*). State *three* possible causes for its formation.

(*d*) State *three* factors which may cause porosity during welding, assuming the joint surfaces were clean before welding was carried out.

(*e*) Calculate the area of the side plate shown as *A* on (*a*).

40 (*a*) State *one* reason why

(1) some welding specifications permit a small amount of slag inclusion in a welded joint,

(2) it would not be realistic for a specification to state that a welded joint must be free from defects,

(3) welding specifications do not permit welded joints containing cracks to be accepted.

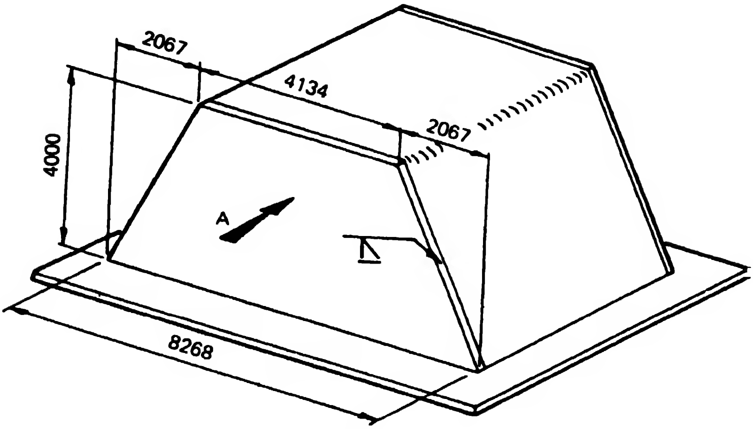
(*b*) Show, with the aid of a sketch, how the design size of a butt weld is measured.

41 (*a*) The figure shows butt and fillet joints which are to be joined by manual metal-arc welding. Explain why the welding specification may state that for the same heat energy input the butt-welded joint would not require to be pre-heated, although the fillet welded joint should be.

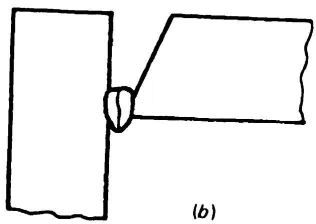
(*b*) The hardness of the gas cut edge shown in '*X*' in (*b*) was found to be unacceptably high. State *three* changes in the oxy-fuel gas cutting procedure that could have been taken to reduce the hardness value.

42 The figure shows a low-carbon steel oil storage tank which is to be fabricated from 18 mm thick low-carbon steel plate using the submerged arc welding process.

Question 39



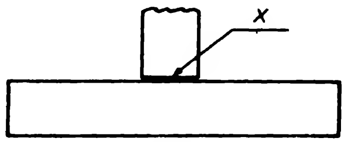
(a)



(b)

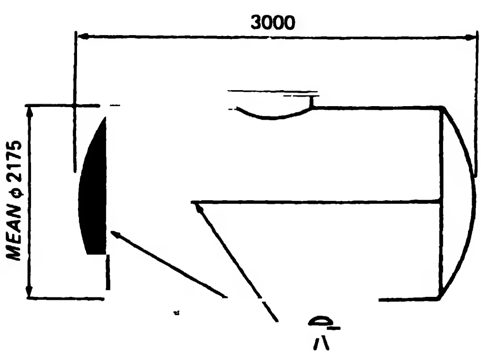
Question 41

(a)



(b)

Question 42

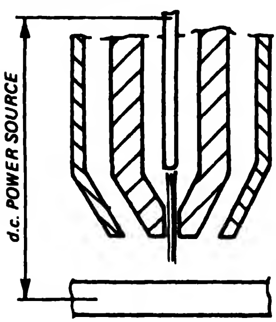


(*a*) Calculate the length of plate required to be gas cut and rolled to form the cylindrical section of the tank.
(*b*) Explain why run-on and run-off plates are used when welding the longitudinal seam.
(*c*) Explain why welds made using the submerged arc welding process usually have a low level of defects.
(*d*) If the weld deposit was required to have good impact properties state whether it would be made with either a large number of runs or as few a number of runs as possible.
(*e*) State *four* variables under the control of the welder which will influence the weld profile.
(*f*) Name *two* other mechanized welding processes that could be used for welding the joints and state in *each* case *one* reason for using the process in preference to the submerged arc process.
(*g*) State in *each* case *one* advantage which may be obtained by using
   (1) alternating current for submerged arc welding,
   (2) direct current for submerged arc welding.

43 In relation to the plasma arc welding process
(*a*) reproduce the sketch shown in the figure and identify the
   (1) negative pole within the circuit,
   (2) shielding gas ports.
(*b*) State whether the parent metal forms part of the welding circuit when a non-transferred arc is used for welding.
(*c*) State a temperature within the temperature range of the arc.
(*d*) Sketch a transverse section through the weld made by means of a transferred arc on low-carbon steel 10 mm thick.

44 (*a*) List *four* variables under the control of the operator which will influence the quality of a resistance spot weld.

Question 43



(*b*) Low-carbon steel sheet has been resistance spot welded. State whether the welding current would need to be increased if this process was to be used for welding aluminium sheet of the same thickness.

(*c*) Describe the operational sequence used for making resistance butt welds in short lengths of 50 mm diameter low-carbon steel pipes of wall thickness 6 mm.

(*d*) (1) A number of steel studs having the form shown in the figure are to be welded to low-carbon steel plate. Describe, with the aid of a sketch, the operational sequence used to make a drawn arc stud welded joint.

(2) The figure shows a ceramic ferrule used in the drawn arc stud welding. Explain the purpose of the serrations.

45 Each term used in column *A* in the table is directly related to *one* of the terms used in the column *B*. Pair *each* of the terms listed in column *A* with its appropriate term in column *B*.

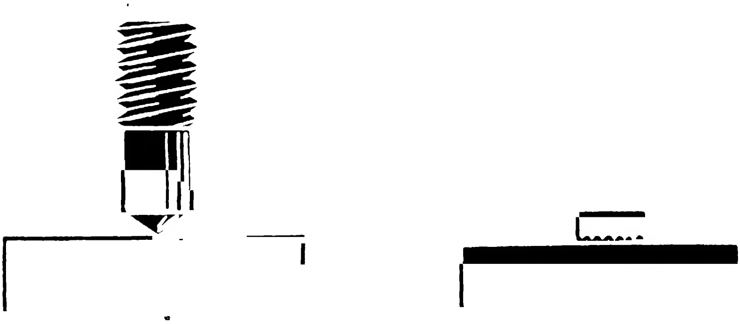
Column *A*	Column *B*
d.c. negative polarity	Force
Nugget	Oxy-fuel cutting
Kerf	Welding standard
API	Resistance spot welding
newton	Hard surfacing

46 A box section column 750 mm square × 6500 mm long is to be fabricated from 40 mm thick low-carbon steel plate.

(*a*) Select and describe a suitable automatic welding process.

(*b*) Sketch the corner joint and show, if necessary, any edge preparation.

Question 44. (*d*) (1)



(*c*) Give *three* advantages of using automatic welding as opposed to manual metal-arc.

47 A spherical vessel, 3.6 m diameter, is fabricated from 75 mm thick low-carbon steel, the welding of the circumferential seams being carried out by the electroslag process.

(*a*) Sketch the macrostructure of the plate and weld area.

(*b*) Describe a suitable method of heat treatment to be carried out on completion of the welding.

(*c*) State *three* advantages to be obtained by the form of heat treatment chosen.

(*d*) State *two* safety precautions to be taken when pressure testing the vessel.

48 (*a*) Explain why the effect of electric shock is much less when using a flat characteristic instead of a drooping characteristic power source for welding.

(*b*) Name *two* gases which may be produced during arc welding operations which are harmful to the health of the welder.

49 (*a*) State *two* factors that should be considered before selecting a filler/electrode for a hard surfacing application.

(*b*) State *three* precautions which may be taken by the welder to control the level of dilution when surfacing using an arc welding process.

50 (*a*) The figure shows three views of a platform bracket. Using graph isometric paper, make an isometric sketch of the bracket in the direction of arrow *A*. Omit all hidden lines.

(*b*) Parts of the bracket are to be assembled and welded using the electrical resistance spot welding process.

(1) Outline the principles of electrical resistance spot welding.

(2) State why the stiffener shown at *B* could not be resistance spot welded for the design shown.

(3) Sketch a modification to the stiffener that would enable spot welding to be used.

(4) State *three* advantages of using the resistance spot welding process for welding the bracket in preference to a fusion welded process.

51 State *five* variables, other than electrode diameter, that will influence the production of an acceptable quality weld when using the mechanized flux shielded visible arc process.

52 Name *each* of the welding or thermal cutting processes illustrated in the figure. Identify your answer by stating the appropriate letter and name the process concerned.

53 (*a*) State *one* safety precaution that must be carried out.

(1) when oxy-acetylene cutting inside a steel container,

(2) when manual metal-arc welding galvanized steel,

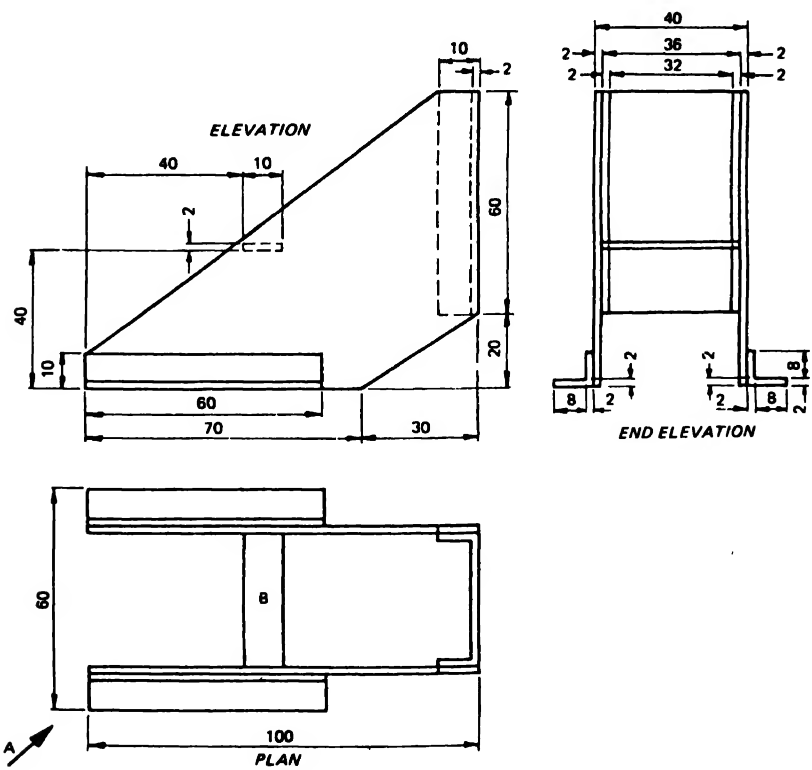
(3) when gas-shielded metal-arc welding inside a container.

(*b*) State why gas-shielded tungsten arc welding should not be carried out inside a container that has been degreased using carbon tetrachloride until all the degreasing compound and vapours have been removed.

54 The figure shows an aluminium–magnesium alloy safety rail which is to be welded by the gas-shielded metal-arc welding process using 1 mm diameter filler wire.

(*a*) State a suitable welding voltage and amperage setting for making the fillet joint shown at *A*, in the horizontal–vertical position.

Question 50



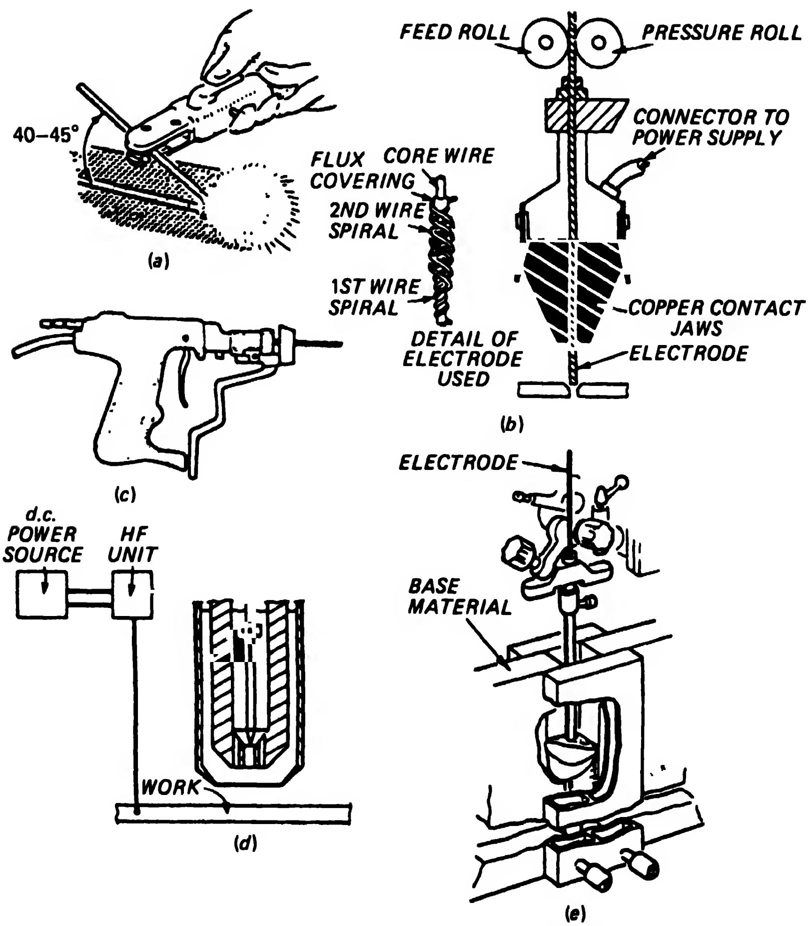
(*b*) Name the mode of metal transfer which would be used for welding *each* of the following:

(1) the fillet joint shown at *A* in the horizontal position,

(2) the fillet joint shown at *B* in the vertical position.

(*c*) When welding aluminium with this process, electrode wire may be supplied by pull feed from the torch or by push feed from a separate wire feed unit. State *two* advantages and *two* disadvantages of *each* method of wire supply.

Question 52

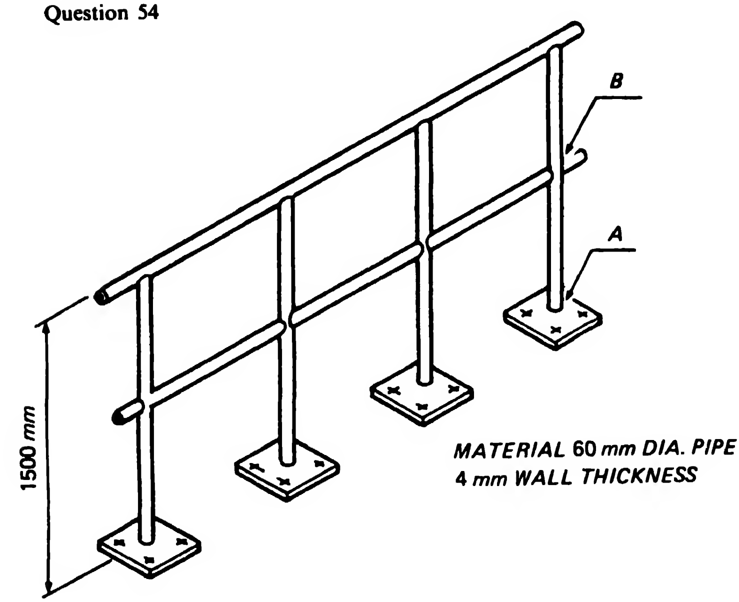


(*d*) List *four* problems which may be encountered when fusion welding aluminium.

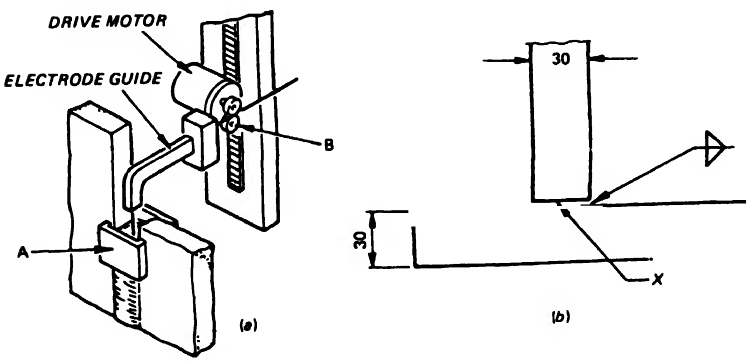
(*e*) State *two* reasons why an 80% argon, 20% carbon dioxide gas mixture should *not* be used as the shielding gas for welding aluminium.

(*f*) Give *two* reasons for using helium as a shielding gas for welding aluminium with the gas-shielded tungsten arc welding process.

Question 54



Question 55



55 The figure (*a*) shows a section of a joint being welded using the electroslag process.

(*a*) Name the parts identified in the sketch at points *A* and *B*.
(*b*) State why run-off plates are required to complete the weld.
(*c*) State whether or not an arc is maintained throughout electroslag welding.
(*d*) Explain why small additions of flux may require to be added during electroslag welding.
(*e*) Give *two* reasons why electroslag welds may require to be heat treated after welding.
(*f*) State *three* basic differences that exist between conventional electroslag welding and consumable guide welding.
(*g*) Sketch in section a cruciform joint made by electroslag welding.
(*h*) Figure (*b*) shows a joint in low-alloy steel set-up for fillet welding using the manual metal-arc welding process. Explain why the edge shown at *X* was oxy-acetylene flame cut, then machined before welding.

56 In relation to welded fabrications:

(*a*) state what is meant by the term brittle fracture,
(*b*) state *five* conditions in which an otherwise ductile steel may behave in a brittle manner after welding,
(*c*) name a test that may be used to assess the notch ductility of a steel,
(*d*) state *five* factors to be considered when selecting a manual metal-arc electrode to be used for a given application.

57 The figure shows a beam to be fabricated from low-alloy steel, using the gas-shielded metal-arc process with flux cored electrode wire.

(*a*) Using the carbon equivalent formula given, calculate the carbon equivalent of the steel beam when its composition is as shown in the table.
(*b*) Explain why steel components with a high carbon equivalent should be
  (1) pre-heated before welding is carried out,
  (2) immediately post-heated after welding.
(*c*) The figure shows that the flanges of the beam have been stiffened using gusset plates. Explain why the corners have been removed.
(*d*) Name the main stress acting on the underside of flange *B* if a load is applied to the beam in the direction of arrow *A*.

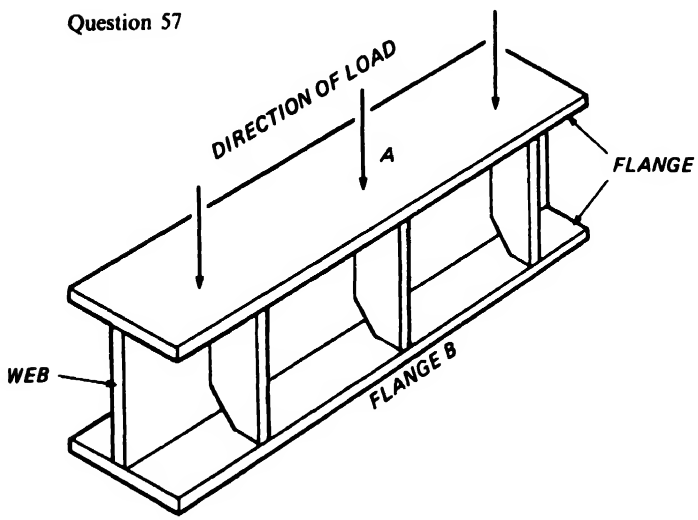
Com-position	Carbon	Manganese	Silicon	Niobium	Vanadium	Remainder/ Iron
As a per-centage	0.22	1.2	0.5	0.1	0.2	Sulphur and phos-phorus in acceptable quantities

$$CE = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mn\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

(*e*) State *four* methods that may be used to reduce undercut at the toes of the welds joining the flanges to the web.

(*f*) Outline, with the aid of a sectional sketch, the effect of using too low a voltage setting for depositing a single run fillet weld by this process.

Question 57



Fabrication and welding engineering (technical grade)

1 (*a*) Give the main feature which distinguishes between cylinders for (1) combustible gas, and (2) non-combustible gas.
(*b*) Explain the function of a 30 A fuse.
(*c*) Why is a cylinder normally rolled to a slight overlap of the butting edges in a plate binding rolls?
(*d*) Show, on an appropriate cross-section of rolled steel member, the correct positioning of a tapered washer.
(*e*) State *four* factors which would ensure good quality soldering.
(*f*) What information may be obtained by an examination of an etched cross-section of a fillet weld?
(*g*) A large triangular plate of 30 mm thickness is lying on a workshop floor. Describe how the plate could be marked off to find its centre of area, for lifting purposes.
(*h*) Give *five* reasons for using false wired edge on thin sheet metal.

2 (*a*) Explain the essential differences between ductility and malleability.
(*b*) What is meant by (1) hardness and (2) toughness? Give practical examples of the use of these *two* properties in different materials.

3 Compare and contrast the following cutting processes: (1) oxy-fuel gas cutting, (2) guillotine cutting, with respect to:
(*a*) cost,
(*b*) limitations of cut,
(*c*) type of material to be cut.

4 Discuss the factors which must be considered when deciding whether to form a given metal by hot or cold processes.

5 Describe, with the aid of sketches, *three* methods of stiffening and strengthening metal platework without the attachment of additional members.

6 When producing a riveted watertight butt joint, what are the important features to look for:
(*a*) when setting up the work,
(*b*) after riveting.

7 Explain the meaning of the following terms when used in connection with the control of distortion in welding:
(*a*) preset,
(*b*) restraint,

(*c*) back-step,
(*d*) intermittent,
(*c*) staggered.

8 It is suggested that the following requirements are essential for safe and adequate electrical circuits in a fabrication workshop:
(1) colour coding,
(2) notices,
(3) maintenance,
(4) notification of faults,
(5) earthing,
(6) load protection,
(7) insulation,
(8) protection,
(9) emergency switches.
Write explanatory notes on any *five* of the above.

9 With the aid of sketches of cross-section show *each* of the following weld defects:
(*a*) undercut on a fillet weld,
(*b*) undercut on a butt weld,
(*c*) lack of root penetration in a fillet weld,
(*d*) lack of penetration in an open square-edge butt joint,
(*e*) excessive root penetration in a single bevel butt joint.

10 One hundred welded fabrications each weighing 48 kgf are at a temperature of 25 °C. They are placed in a furnace and heated to 500 °C for the purpose of stress relieving. Calculate the quantity of heat to be supplied so that the fabrications reach the required temperature. Specific heat capacity of the welded fabrication is 0.5 kJ kg °C. Furnace efficiency is 20%.

Index

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